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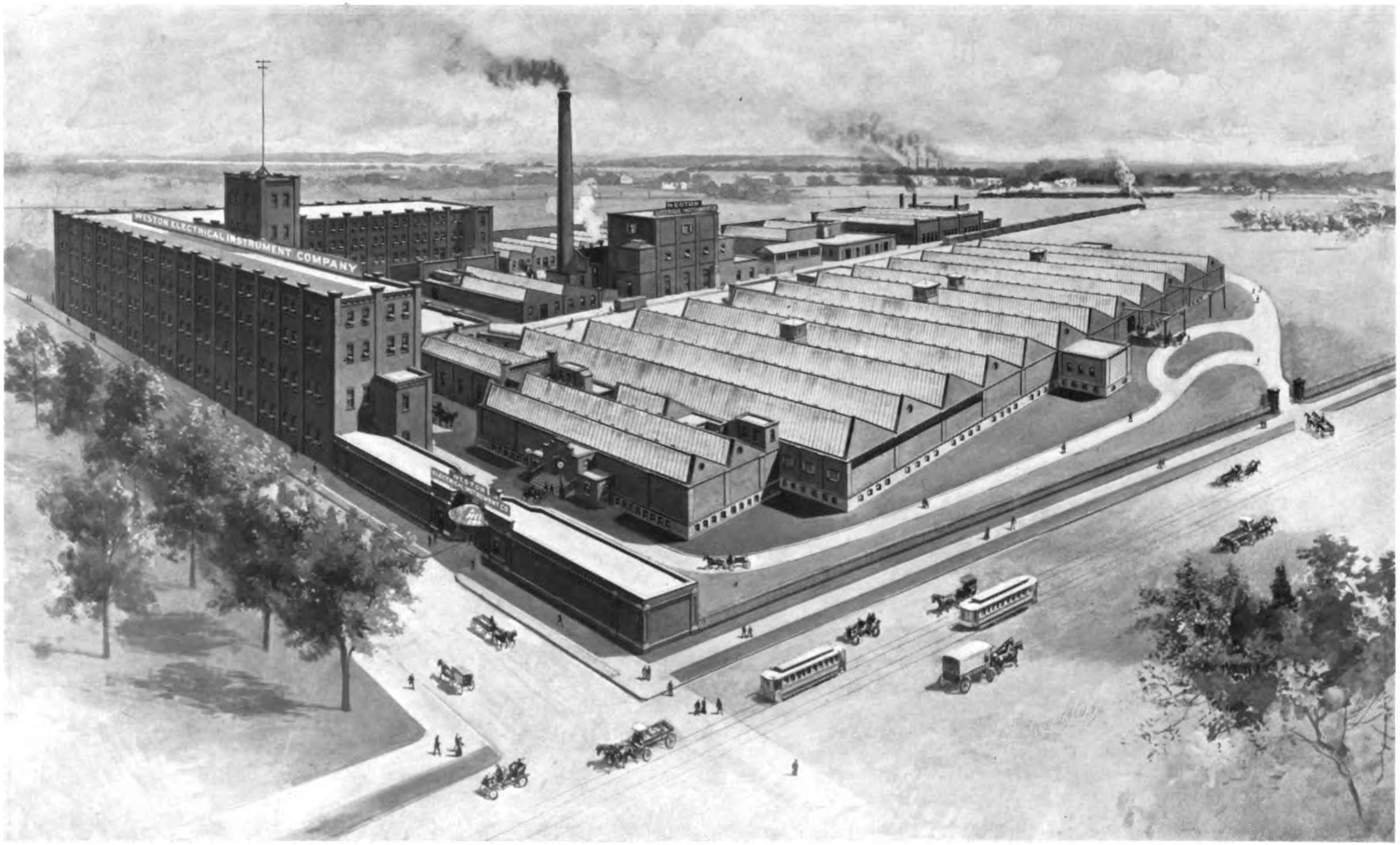

Main Office and Works of the Weston Electrical Instrument Company

WESTON
ELECTRICAL INSTRUMENTS
FOR USE ON
ALTERNATING-CURRENT SWITCHBOARDS

A COMPLETE LINE OF
A. C. SWITCHBOARD
INDICATING INSTRUMENTS

CATALOG 16

WESTON ELECTRICAL INSTRUMENT COMPANY
NEWARK NEW JERSEY
1911

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Announcement

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IT is with great pleasure that the Weston Electrical Instrument Company announces the introduction of a new group of alternating-current instruments, which, in conjunction with the soft-iron instruments brought out in 1907, now enables it to supply a complete line of indicating electrical measuring instruments for alternating-current stations.

This complete group of apparatus now includes: Single-phase and polyphase wattmeters; synchroscopes; power-factor meters; frequency meters; alternating-current voltmeters and ammeters; direct-current voltmeters and ammeters; all mounted in round pattern cases similar in appearance and having the same base dimensions.

Although the Weston Electrical Instrument Company has for many years been building and studying various types of alternating-current switchboard instruments, it has always persistently refused to put any of the many intermediate types officially on the market. This action was, and is, in accordance with a firmly established Weston policy of not experimenting on the public. Weston products are developed in the Weston laboratories entirely at the expense of the Company, and no instrument or appliance is put on the market until it is in its final form and has stood every test that it will ever undergo in the course of general engineering work.

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Instruments for Use on A. C. Switchboards

SECTION 1

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Introduction

IT is very difficult for the average engineer to realize fully the value of perfect indicating instruments in the operation of a plant, therefore many still look upon the extensive use of high-grade instruments as an extravagance, while comparatively few believe that accuracy is at all essential in this class of measurement. Nothing could be further from the truth.

Use of Indicating Instruments

Integrating instruments, which give the total energy output, are important in accounting for the total production of a plant; recording instruments, which record the load fluctuations, are important in determining the load-factor, and also they serve to give a general idea of how many units will be required from hour to hour and from day to day, so that they may be ready for operation when the time comes. Both of these classes are important, but they are useful merely as records. Indicating instruments, which show the instantaneous condition of the load, give information which forms the basis of economical and safe plant operation. The conditions essential to maximum economy and safety of operation can be ascertained only by the use of good indicating instruments.

Integrating instruments—watt-hour meters—furnish information to the accounting department, recording (graphic) instruments serve the engineer in planning ahead, and indicating instruments guide the operator in attaining and maintaining conditions of maximum economy and in safeguarding the plant. Therefore, indicating instruments are of equal if not greater importance than either integrating or recording instruments.

Requirements of Switchboard Instruments

If an indicating instrument is to fulfill its purpose, it must be accurate, reliable and durable. It must be substantially unaffected by any variable conditions, except those it is intended to measure, and finally, it must be able to indicate the true conditions in a circuit, independent of whether the load on that circuit is steady or fluctuating.

If an instrument is to fulfill this last requirement, it must have a high ratio of working torque to weight of the movable system and it must be effectively damped. Therefore, the result can be attained in two ways, namely, by increasing the torque, or by decreasing the weight.

High-torque instruments should be regarded with suspicion, as high torque signifies great weight and therewith large friction torque and inferior durability. They also require heavy and powerful dampers to render their motion dead beat.

In all Weston instruments a high ratio of torque to weight is attained by reducing the weight and by properly distributing the masses of the movable system. Such a movable system also lends itself readily to efficient damping.

Torque Weight and Life

Exhaustive tests have shown that, other things being equal, the useful life of an instrument varies inversely approximately as the square of the weight on the pivots: that is, if in one instrument the movable system weighs twice as much as that in another, the latter will last approximately four times longer than the former. Furthermore, the durability of an instrument being in almost every case determined by the wear of the pivots and jewels, should be inversely proportional to the amount of motion; that is, the life of an instrument is prolonged by effective damping, which eliminates all useless motion.

The whole question of the influence of unnecessary mass, or of improper distribution of mass in the movable parts of electrical measuring instruments, in causing error in their indications under the most varied conditions of practical use; or of producing unnecessary wear and tear on the pivots and jewels; or in subjecting the movable system to undue and frequently injurious or even destructive strains, is far too complicated to present in a bulletin or catalog. It may be said, however, that the degree of perfection attained in the reduction and distribution of mass may be judged by the general excellence of an instrument, and that extreme accuracy under the very varied conditions of general service is an unfailing indication of high quality and very great durability, since it can be attained only by the most perfect design and skillful construction.

Weston Switchboard Instruments

The Weston switchboard instruments which form the subject of this catalog, fulfil every requirement of good switchboard instruments as set forth above. Their indications are accurate within the limits of scale reading, independent of all variations in surrounding conditions, and, furthermore, the accuracy of reading is substantially the same on fluctuating loads as on steady loads.

The individual characteristics of these instruments are described in the following sections of this catalog; however, it may be said here, that each one of the instruments in this new group constitutes a distinct advance in the art and that, as a class, they are the only scientifically designed alternating-current switchboard instruments now on the market.

These are, indeed, very sweeping statements, but they have not been made without due consideration, and those who are familiar with Weston methods know that the Weston Electrical Instrument Company does not make claims for its products that cannot be completely established.

Weston Reliability

The Weston Electrical Instrument Company has been building electrical instruments for about a quarter of a century, and in that time it has gained a world-wide reputation for the originality of its work and the excellence and reliability of its products. When it brings out an instrument that instrument is a finished product, and can be relied upon to do its work in a thoroughly satisfactory manner, and the purchaser can rest assured that it will not be soon withdrawn from the market to make way for a new model.

This Company has standardizing and investigating laboratories, which rank second to none in the world, both as to equipment and as to value of their work to the engineering profession. No experimenting is done at the expense of the public; all this is completed and the instrument perfected in every detail before it is put on the market.

For the benefit of those who are not familiar with the business methods of the Weston Electrical Instrument Company, it may be well to say a few words regarding the origin of the Company, and by a brief exposition of facts bring out the exact relationship of the Company to the user of electrical measuring instruments.

Origin of the Weston Electrical Instrument Company

The Weston Electrical Instrument Company was organized to exploit, and has developed around, the ideas and labors of Dr. Edward Weston, the founder and president of the Company. Dr. Weston was actively engaged in the early development of practically every branch of electrical engineering. In fact, the present practice in electrotyping, electroplating, arc and incandescent lamp manufacture and lighting, dynamo design, etc., rests largely, and in some instances entirely, upon the early work done by him.

Dr. Weston has always been a firm believer in precision methods of manufacture and all the many processes which he has developed have included a careful control of the product by systematic mechanical and electrical measurements. No appliance was ever put on the market until every factor entering into its design was carefully investigated and quantitatively determined. For instance, while the other people were building dynamos and throwing them into the scrap heap, he was turning out a machine having an efficiency of 96 per cent! As early as 1877 he was building four machines per day, and most of them are still in service.

Through all this early work Dr. Weston was obliged to build his own measuring instruments and appliances. He built tangent galvanometers, voltage and current indicators and various other measuring devices, and many of them were put on the market.

Being actively engaged in the design of commercial lighting and power plants Dr. Weston realized fully the great need of measuring instruments suitable for this kind of work. With this demand in mind, he began a long series of exhaustive investigations with the object of developing a line of direct-current indicating measuring instruments which should be accurate and reliable in operation and durable in construction. After years of work and the expenditure of large sums of money, he presented to the world the famous Weston permanent magnet instruments, and it was to manufacture this type of instrument that the Weston Electrical Instrument Company was organized early in 1888.

Since that time Dr. Weston has applied practically all his energy to the advancement of the art of electrical measurement, and under his direction one instrument after another has been developed and put on the market. Every one has promptly taken its position as the best of its class, and has been extensively imitated by the leading instrument makers in every civilized country.

How Weston Instruments Are Developed

The steps in the development of a Weston instrument may be roughly outlined as follows: First, every variable—and often there are fifty or sixty—is tabulated, then each one is analysed and the analyses summed up so as to show the general trend of design which will reduce the undesirable factors to a minimum and increase the desirable ones to a suitable maximum. Following this preliminary study, experimental models are built and the complex relations of all the factors studied and quantitatively determined.

Perhaps the attainment of the desired results is rendered impossible by the lack of materials having the required physical properties. This limitation, usually assumed to be insurmountable, is not recognized here, but simply leads to an exhaustive study of materials, involving investigations of the very highest order. How often this limitation has been encountered can be judged from the fact that nearly every material used in Weston instruments is especially prepared for the purpose. In the course of this great investigation work, which has been going on now much over a quarter of a century, Dr. Weston has invented and thoroughly studied between 3000 and 4000 alloys for use with measuring instruments. Manganin, the so-called zero-temperature-coefficient alloy, which is universally used in the construction of resistors by the leading instrument makers of the world, is one of the early alloys invented by Dr. Weston. His first patents on this alloy were applied for in April, 1888.

These investigations frequently go on for years before the final model is arrived at, and during this time all construction work is done by highly skilled mechanics. Having brought every detail of a type to the required degree of perfection, the next step is the development of a manufacturing system. Tool operations are planned, tools are built and devices for determining every dimension and measuring the magnitude of every force are constructed.

After the manufacturing system is perfected, manufacturing is begun and a large stock is accumulated, so that orders can be filled promptly as soon as the instrument is announced to the public.

This is, indeed, a thorough-going and broad-minded policy, and although it requires an enormous capital investment, it establishes this Company on a permanent foundation and distinguishes it as an institution for the advancement of the art.

Weston Quality

Weston instruments are accurate, reliable and durable; they fully meet every requirement of the service for which they are intended. It would be utterly impossible to construct instruments having an equal degree of precision that could be sold at a reasonable price, except in a factory fully equipped with special tools for manufacturing each and every part to dimensions correct within the required limits. Further, in order to avoid any possible errors due to accidents or to imperfections in the material or tools, special devices must be provided for gauging every dimension, so that all operations can be checked and maintained within the prescribed limits of accuracy.

There is no factory in the world that can compare with that of the Weston Electrical Instrument Company as to completeness of equipment and system. It would be impossible to devote sufficient space here to give even a general idea of the wonderful system of manufacture developed by Dr. Weston for producing instruments of precision on a truly commercial scale and with every effort made for the practical elimination of the personal equation of the workmen. The best way to get a general idea of the perfection of this system is to consider the high quality of the results attained.

Each and every part of all Weston instruments is interchangeable. The parts are manufactured, gauged and put into stock; then they are taken from stock and instruments assembled absolutely without cutting and trying.

The absolute interchangeability of Weston instrument parts speaks for itself. It can be attained only by perfect workmanship and practically absolute uniformity of material, and every precaution is taken by the Weston Electrical Instrument Company to insure the fulfillment of these two requirements. All materials are tested before they are used; all parts are tested and gauged at every stage in their manufacture up to the time they are put into stock; all instruments are tested when they are assembled; just before they are shipped they are again checked, and as a final protection to the purchaser every instrument is guaranteed to be just as represented, and if any defects in the construction develop the instrument will at once be replaced by a new one.

How Weston Quality is Maintained

The Weston Electrical Instrument Company always has the user's welfare in view; every precaution is taken to safeguard his interests and render maximum service at minimum cost to him. As an example of this, may be cited the infinite care that is exercised to maintain the fidelity of all standards. Every tool and gauge has a master gauge, and sometimes several, made at the same time the first tool was put into service, and by continual comparison with their master gauges the accuracy of all tools and working gauges is maintained irrespective of changes due to wear or accidents. All standard gauges and master plates are stored in a fireproof vault and handled with the greatest care. The actual efficiency of this elaborate system may be judged by the fact that a part made to-day will fit perfectly in an instrument made twenty or more years ago.

Users Interests Safeguarded

The extent to which the Weston customer is safeguarded is evidenced to a still greater degree in the method pursued in the introduction of improvements after an instrument is once on the market. The Weston Electrical Instrument Company never stands still, therefore there are always advances in the art. New materials are discovered or new processes of manufacture are invented, which enable an instrument to be brought nearer to theoretical perfection, and, therefore, in justice to all, these improvements must be embodied in the instrument, even though it be already on the market. The usual way among instrument manufacturers is to get out a new model replacing the previous ones, and when one of the old models is returned for repairs, the customer is informed that the instrument is out of date and that he had better buy a new one. This is not the way Weston instruments are improved.

As was said above, the name Weston stands for originality, and "Weston originality" is well exemplified in the method of improving Weston instrument models. When a change is made to care for an advance in the art of construction, every effort is exerted so to embody that change that it may be applied to the earliest instruments of that model with minimum cost to the customer and without any sacrifice of good results; then when an old instrument is returned, the latest improvements can be, and are, inserted into it without any cutting or trying, and the instrument goes back to its owner not simply repaired, but brought absolutely up to the highest state of the art at that time.

Weston Record System

The Weston system is not satisfied with merely developing and producing instruments which represent the highest standards of attainment, but it also follows its products closely throughout their lives. For instance, every appliance manufactured by the Weston Electrical Instrument Company since its beginning has its important constants, and its history, as far as the company knows it, recorded and kept on file. Before an instrument is shipped the record of its life is begun. The constants, such as resistance of windings, strength of magnetic forces, strength of springs, etc., are determined and recorded; the date and destination of shipment and the name of the owner are noted; and, in fact, by means of this record system used in conjunction with others, the source of all material used, the exact process of manufacture, and the number of every tool employed in its construction can be ascertained. Whenever an instrument is returned for calibration or repairs, it is sent at once to the repair laboratory, where its condition is carefully noted and recorded. If any of its parts are damaged they are renewed, and if it happens to be in an operative condition, it is tested and its constants compared with those in the original record. The resistance is determined in all cases where the circuits are not burned out. Sometimes instruments come in for calibration after more than twenty years of active service; the official value of the volt has changed four times during the time they have been in operation. Such instruments furnish much valuable information. They also show what may be expected from a Weston instrument when a reasonable amount of care is exercised in its use.

Having put an instrument into operative condition and calibrated it in accordance with the latest official standards, a complete account of what has been done to it and whatever additional information that may be of interest, is recorded and placed on file.

By this record system the Company has acquired accurate, detailed and comprehensive knowledge of the complex factors affecting the durability and reliability of instruments under the actual conditions of commercial work. Furthermore, it has furnished the Company valuable information about the conditions of misuse and accidents, and also has shown which users are careless or ignorant and which are not. The valuable and useful information furnished by these records has been of great assistance to the Weston Electrical Instrument Company in advancing the art of electrical measurement, and in the light of this vast experience it goes on developing and improving its products and the user receives the benefit.

SECTION 2

Weston Electrodynamometer Instruments

THE first successful direct-reading indicating electrodynamometer instrument was invented by Dr. Edward Weston in the late eighties, a patent being applied for in January, 1890. Not only is the world indebted to Dr. Weston for the creation of this type of instrument, but it is also indebted to him for every single advance in the progress of its development up to the present and final form as exemplified by the latest Weston electrodynamometer instrument.

Early Weston Electrodynamometer Instruments

The first Weston electrodynamometer instrument was a portable voltmeter. A view of the working parts of one of the earliest voltmeters of this type is shown in Fig. 1. A hasty inspection of this illustration will show that this instrument, though built over twenty years ago, embodies all the essential elements which go to make up the modern instruments of this type, and, were it feasible to devote sufficient space to it here, we could easily demonstrate that, in design, these early instruments were far superior to anything now manufactured by other makers.

Unusual care was taken in designing, and especially in proportioning and constructing, each part for the purpose of securing the best general result. The movable system was extremely light and had a very low moment of inertia, and at the same time its strength was sufficient not only to serve the purpose of its proper use, but also to have an adequate margin of safety to provide for a reasonable degree of abuse due to accidental misuse of the instrument. After a few years a number of important changes were made in this instrument, which resulted in a reduction of the weight and moment of inertia of the movable system to previously unheard of values. The pointer and counterbalance were constructed to form a cross, and their combined weight was only 0.065 gram. However, notwithstanding the extreme lightness of these parts, they were much better able to withstand abuse due to misuse than the corresponding and heavier parts of the earlier instruments. The complete discussion of the wonderful construction of these early instruments is a task that must be reserved for a later publication. It is mentioned here merely to call attention to the true origin of this type of instrument.

The voltmeters were quickly followed by wattmeters designed along the same lines. The voltmeters were designated as Model 18 and the wattmeters as Model 16, and both are well known to laboratory engineers and others who have used them as secondary standards in alternating-current measurements.

These early portable electrodynamometer instruments have played an exceedingly important part in the development of alternating-current engineering and design, and practically every instrument maker in the civilized world has evidenced his admiration of Dr. Weston's work by imitating, in a more or less crude way, every form of electrodynamometer instrument that has ever been brought out by the Weston Electrical Instrument Company.

Soon after the portable instruments were placed on the market, Dr. Weston designed a switchboard form of the same type; however, it was found impossible to produce a generally useful and reliable instrument with its axis of rotation in the horizontal plane, this being due primarily to the necessity of eliminating friction, which, in instruments intended for general use on commercial circuits of varying frequency, is especially difficult. The torque in an instrument of this class must be kept low, if good results are to be attained, and because of this no appreciable friction can be tolerated.

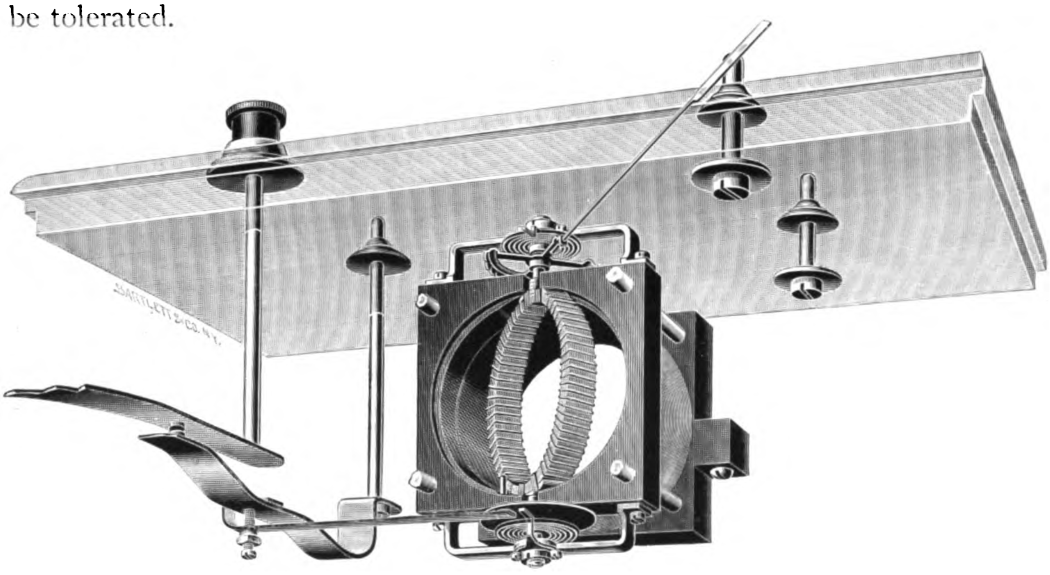

Fig. 1. First Successful Electrodynamometer Instrument

Weston Horizontal Edgewise Instruments

To get around these difficulties, Dr. Weston, in 1896, invented the first horizontal edgewise indicating instrument, a patent for which was applied for by him early in 1898. The original type of horizontal edgewise wattmeter is shown in Fig. 2. No attempt was made to save space on the switchboard; this form was adopted solely to reduce friction. The load on the lower bearing was reduced by immersing the whole movable system in oil, which also served to damp the motion and render the indications dead beat. By use of the oil the weight on the pivot was decreased by fully 30 per cent. This model has been built and sold for years, and a number of these instruments are in operation. However, they were never advertised, because Dr. Weston was not willing to consider the horizontal edgewise instrument as a satisfactory solution of the indicating wattmeter problem.

Other makers were quick to take up the horizontal edgewise expedient, and in order to make capital out of this defective form, they have advocated it because of the saving of space on the switchboard. However, this slight saving in space is gained only at the expense of accuracy and facility of reading, since, on account of the curvature of the scale, it is impossible to read such an instrument from any position except directly in front of the pointer.

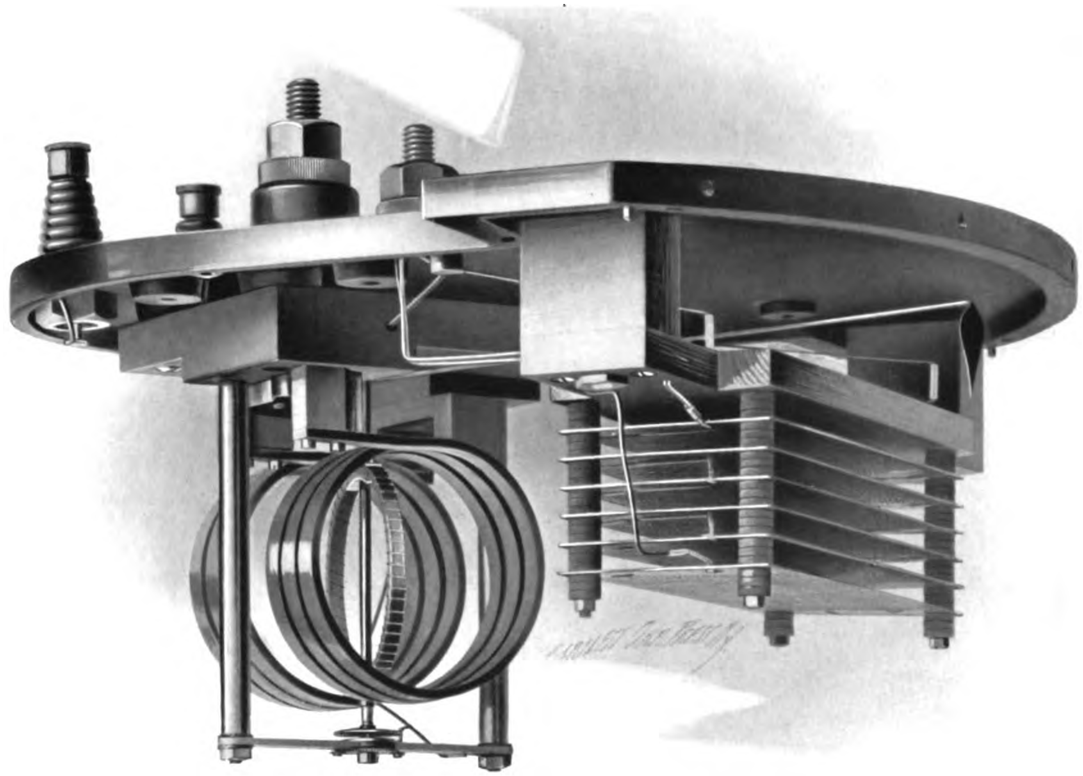

Fig. 2. First Horizontal Edgewise Switchboard Wattmeter

The Perfected Weston Electrodynamometer

The Weston electrodynamometer in the form now offered is a triumph of persistent scientific research and investigation. It represents the highest state of the art of instrument design, and the results attained with it are far in advance of anything heretofore accomplished.

This new electrodynamometer movement has been applied to three distinct lines of alternating-current switchboard instruments, namely: wattmeters; synchroscopes, and power-factor meters. In mechanical construction all three are substantially alike; the wattmeter and synchroscope are practically identical, while the power-factor meter differs from them only in certain details. Therefore, in dealing with the construction of these instruments, every purpose will be served by confining the general remarks to the wattmeter, and then, at the proper points, to take up those details of the other two instruments in which they differ from the wattmeter.

General Assembly

The general appearance of the movement and the relative position of the various parts is clearly shown in Fig. 3, which is a view of a single-phase wattmeter with the cover removed. The operative parts are all assembled on one base, which is fastened to the back of the case by two stud bolts. By removing these two bolts the whole movement can be taken out without disturbing the resistors or the switchboard connections. The construction throughout is extremely simple and accessible, with the result that damaged parts can be quickly replaced with minimum expense to the user.

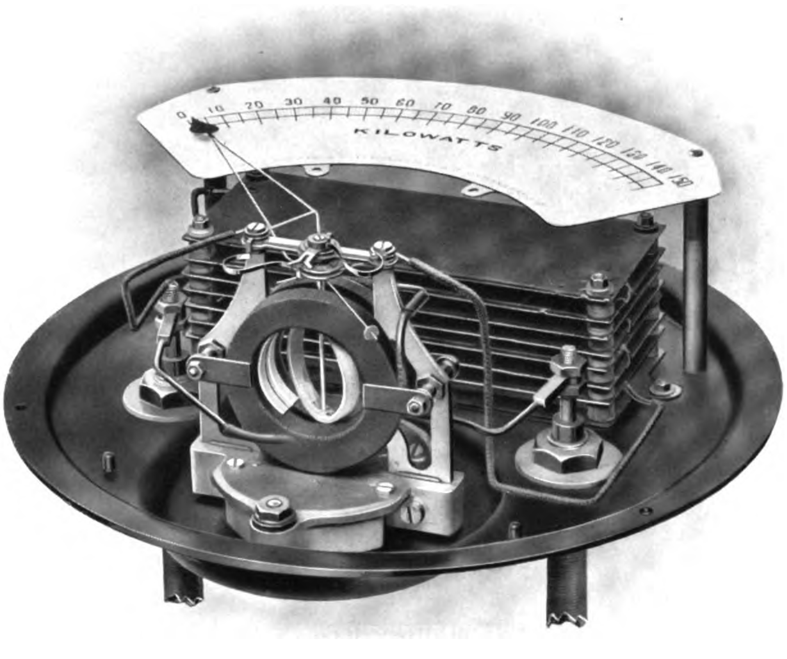

Fig. 3. Interior of Model 167 Wattmeter

Field Coils

The fixed winding is made up of two coils, which act together to produce the field of the wattmeter. These coils are accurately centered by the internal flanges shown in Fig. 5, and their perfect alignment is attained by securing them firmly against the parallel sides of the field-coil supports, which are made to gauge for this purpose.

The field coils of the synchroscope are very similar to those of the wattmeter, except that they are wound with much smaller wire; however, those of the power-factor meter are quite different; they are held in position in the same general manner, but instead of being circular they are somewhat elongated, as may be seen in Fig. 4, which shows the assembled movement of a power-factor meter.

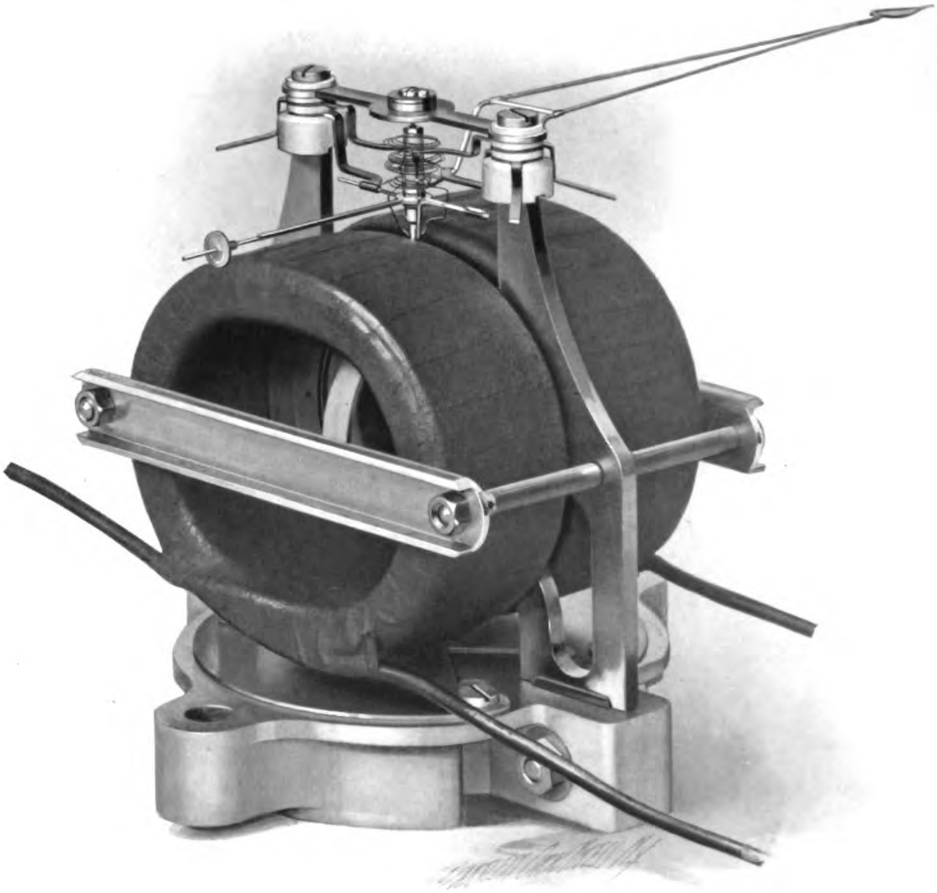

Fig. 4. Working Parts of Model 215 Power-factor Meter

Field Coil Supports

The field-coil supports, shown separately in Fig. 5, serve to support the coils and the bridge, and to maintain accurate relations between the various elements of the system. They are punched from gauged sheets of special high-strength, high-resistivity alloy, which gives great rigidity of construction with minimum mass of material.

Tenons projecting from the lower edge of the coil supports fit accurately into tapered slots in the base, where they are firmly held by bolts, as shown in Fig. 5. To avoid weakening the supports, and also because of the difficulty of machining them, plates of softer metal are soldered to the sides of the tenons, and these are machined to fit the tapered slots. By this construction the coil and bridge supports are given a definite and fixed location with reference to the base which is highly essential to the perfect interchangeability of all parts.

The field coils are accurately centered by arc-shaped flanges, which are recessed into the coil supports and secured in place by metal eyelets. The recesses are made deep enough to prevent the coil from touching the side of the flange, which would be liable to destroy the alignment of the coils, as fixed by the surface of the supports themselves.

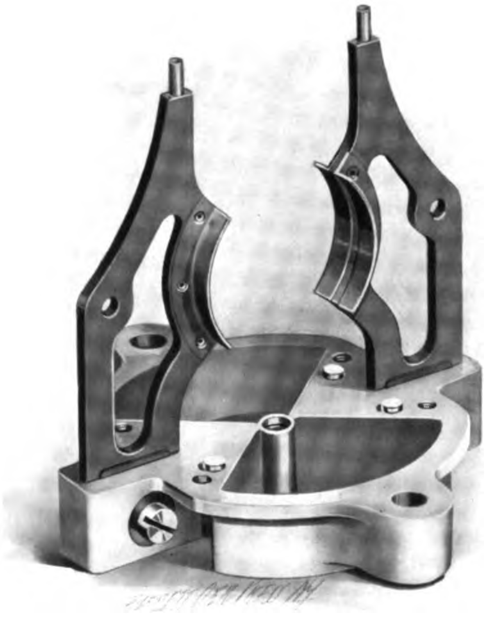

Fig. 5. Base and Coil Supports of Model 167 Wattmeter

The coil flanges of the power-factor meter are bent in the reverse direction from those in the wattmeter, because of the elongated shape of the coils, and, therefore, in this case, there is no necessity for recessing the flanges. This construction is shown plainly in Fig. 6.

In the design of electrodynamometer instruments for use on alternating-current circuits, eddy currents have always given a great deal of trouble, and the greatest source of this trouble is in the standards which support the field coils.

Eddy currents in metallic masses within the instrument produce corresponding eddy fields which modify the main working field both in magnitude and time-phase, thus causing an error in the indications of the instrument. This error varies with the power-factor of the load, and, therefore, in a good commercial instrument it must be eliminated. In the new Weston electrodynamometer instruments, by virtue of the small mass, the high resistivity and the form of the standards, eddy currents are reduced to a truly negligible quantity.

Movable Coil

The movable coil is wound to gauge with silk-covered wire and treated with a special cement, which gives it astonishing rigidity. While winding, the coil is spread at diametral points to allow the insertion of the staff, which is accurately centered by means of two curved plates cemented to the inside surface of the coil and forming a part thereof. The coil is held in a definite position by two tiny pins which pass entirely through the staff and engage with ears on the above-mentioned curved plates, as shown in Fig. 7. This method of construction renders the coil perfectly interchangeable without disturbing the adjustment of any other part of the movable system, since every other part is also definitely located by some equally positive means.

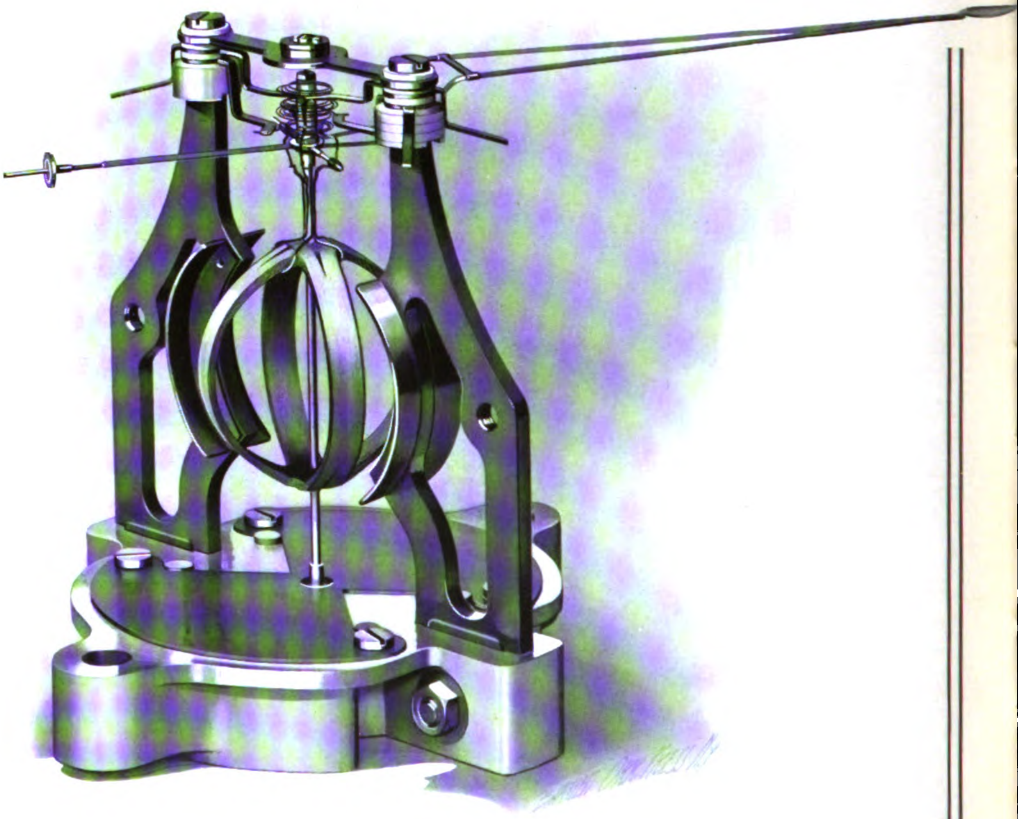

Fig. 6. Movable System and Coil Supports of Model 215 Power-factor Meter

The movable system of the power-factor meter consists of two movable coils perfectly interlaced at diametral points and firmly fixed with reference to each other, as shown in Fig. 6. By a special process these coils are wound in planes at right angles to each other and are interlaced layer for layer, so that their magnetic moments are practically equal.

Trussed Pointer

A vital and most important part of an indicating instrument is the pointer, and especially is this true of indicating instruments for use on alternating-current circuits. In the new Weston alternating-current instruments the pointer has, for the first time, been accorded its full measure of attention, and after much careful study and investigation a novel type of construction has been developed, by means of which all undesirable factors have been reduced to a practical minimum.

The pointer itself consists of a triangular truss with tubular members, an index tip of exceedingly thin metal being mounted on its outer extremity. The index tip is stiffened sufficiently to withstand the severest use by a rib following its contour, which is stamped into the metal and thus adds no extra weight.

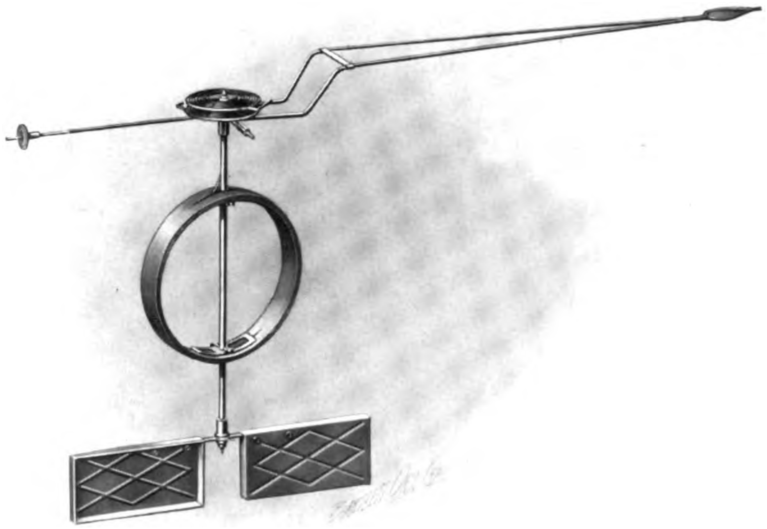

Fig 7. Movable System of Model 167 Wattmeter

As shown in Fig. 8, the pointer is permanently joined to the balance cross, which consists of a flat center webb provided with two short arms and one long one, each arm carrying a nut by means of which the balance of the system may be adjusted. The longest arm, which is opposite the pointer, carries an improved form of balance nut, consisting of a thin walled sleeve provided with a relatively large flange at its outer end. By thus concentrating practically the entire mass of the counterbalance in a flange, maximum advantage is taken of leverage and thus the total weight is reduced to a minimum. The sleeve is tapped with 272 threads to the inch, and, therefore, one turn of the nut will carry the weight $\frac{1}{272}$ inch. The internal diameter of the sleeve is made slightly smaller than the outside diameter of the screw, and the sleeve is split lengthwise; therefore, when sprung into place and properly adjusted it will remain permanently in its correct position unaffected by any conditions incident to general use.

A sleeve which is forced over the end of the staff carries the pointer firmly clamped between a flanged shoulder and a nut. By perforating the webb plate of the balance cross with a hole having two flat sides that fit snugly over a similarly shaped portion of the sleeve, the pointer is given a definite and permanently fixed angular position.

Resonant Vibration

The pointer construction described in the foregoing paragraphs constitutes an important advance in instrument design. It is a most remarkable fact, that by correct design, the pointer has been rendered entirely free from resonant vibration throughout any commercial range of frequency, and yet, at the same time, its weight and moment of inertia have been reduced to extremely low values. It is an easy matter to prevent resonant vibration by piling on weight, but this is a poor expedient, since it involves a great sacrifice of sensitiveness to rapid changes in load, and thus unfits the instrument for use on circuits carrying fluctuating loads, besides materially shortening its life.

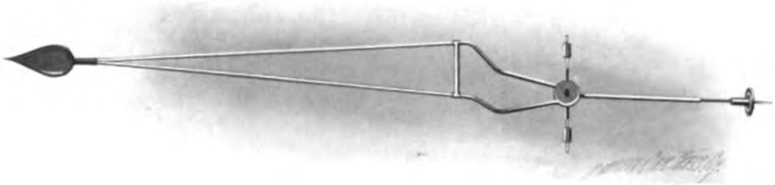

Fig. 8. Pointer and Balance Cross of Model 167 Wattmeter

The design of a system that shall have no resonant point within any commercial range of frequency, and yet be light and have a low moment of inertia, is a problem of no mean proportions, and, as a matter of fact, the first and only successful solution of this problem is embodied in the construction described herein. The tubular triangular truss gives the requisite stiffness necessary to increase the natural frequency beyond the limit of commercial practice and yet keeps the mass and moment of inertia at extremely low values.

The movable systems of many commercial instruments of ordinary construction are set into violent oscillation by even slight departures from the frequency at which they were adjusted, and this constant oscillation is frequently assumed by the user to be due to fluctuating loads. The Weston alternating-current instruments have no resonant point within the commercial range of frequency; as a matter of fact, they can be operated at any commercial frequency between 15 and 900 cycles per second without the slightest trace of vibration.

Damper Design

The damper is also a vitally important part of an indicating instrument, and like the pointer, it has never before been given the amount of serious consideration that it deserves. If a switchboard instrument is to perform properly its functions it must be able to indicate the exact value of the load at all times, independent of whether the load is steady or fluctuating. To do this, the movable system as a whole should be light and the masses so distributed as to give minimum moment of inertia, and the damper must prevent all unnecessary oscillation of the pointer about its true position.

The design and construction of an efficient damper, that is, one that renders all movements dead beat and yet does not add appreciably to the weight or inertia of the movable system, is one of the most complex problems in instrument design.

There are three types of damper in general use in commercial electrical instruments, namely: the eddy-current or magnetic damper; the oil damper, and the air damper.

Eddy-current Damper

The eddy-current damper depends for its action upon the torque required to move a conductor through a magnetic field, and the magnitude of the torque depends upon the strength of the magnetic field, the conductance of the moving conductor and the speed at which the motion takes place. All three of these factors are seriously limited in their application to electrodynamometer instruments. Space limitation and the necessity of keeping external fields and closed metal circuits away from the working field of the instrument require the use of small and weak permanent magnets for producing the damping field. Therefore, the magnetic field being weak, the damping effect can only be attained by increasing one or both of the other factors, namely, the conductance of the movable parts and the speed of cutting the flux. To increase the conductance of the damper disk it must be increased in weight, and to increase the speed of cutting the flux, the disk must extend further from the axis of rotation, which involves increased weight and greatly increased moment of inertia. Thus it is seen that the eddy-current damper is inherently defective, since every move made to increase the damping effect is accompanied by an increased necessity for damping and a disproportionate increase in weight, which means an enormous sacrifice in durability of the instrument.

Oil Damper

The oil damper is limited in its application by the difficulty in handling the oil. In the horizontal edgewise type it can easily be applied. A good example of an efficient oil damper is the one used in the Weston horizontal edgewise voltmeters and wattmeters. A large part of the movable system of these early instruments was entirely immersed in oil, therefore the oil not only acted as a damper, but it also lightened the weight on the pivots, preserved the insulation and kept the movable parts in good condition. However satisfactory an oil damper may be in an instrument with its axis in the vertical plane, it is quite impracticable to employ it in an instrument which has its axis in the horizontal plane, and therefore its use should be strictly confined to horizontal edgewise instruments.

Air Damper

The air damper has none of the inherent limitations mentioned in the preceding paragraphs. It depends for its action upon the compression of air on the advancing side of a vane and the rarefaction of air on the receding side. In open air this action is scarcely perceptible, and even when enclosed in a chamber, the damping force is very slight unless the resistance to leakage from one side of the vane to the other is made very great.

The total damping force of an air damper may be increased in three general ways:

1. By increasing the area of the vane.
2. By increasing the speed of the vane.
3. By increasing the resistance to leakage around the vane.

The first two methods are simple and easy in application, and either one or both are in universal use among instrument makers. However, these methods are both fundamentally defective, since every increase in damping force is offset by increased weight and increased moment of inertia.

The third method is the difficult but the only correct one. By increasing the leakage resistance, that is, by retarding the passage of air from one side of the vane to the other, the degree of compression and rarefaction may be enormously increased, and thus the total damping force augmented without adding weight or increasing the moment of inertia. However, the practical utilization of this method offers great difficulties and it was only after exhaustive investigation that Dr. Weston finally succeeded in overcoming all of them and was thus enabled to produce a practically and theoretically perfect damper. Some of the most important features of this design will be touched upon in the following general description of the construction.

Weston Air Damper

The working parts of the Weston damper consist of two very light symmetrically disposed vanes, which are enclosed in chambers made as nearly air tight as possible. These vanes are formed of very thin metal stiffened by ribs, stamped into them and by the edges, which are bent over to conform to the surface of the side walls of the chambers. They are attached by metal eyelets to a cross bar carried on a sleeve similar in construction to the one at the upper end of the staff.

This cross bar is held in place by a nut, as shown in Fig. 7, and is provided at the center with a hole having two flat sides, being similar in shape to the one in the balance cross (see Fig. 8). This hole likewise fits over a sleeve and definitely locates the vanes with reference to the other parts of the system.

The damper box is cast in one piece to form the base that carries the field coils and the movable system, and the chambers occupy space which would otherwise not be utilized. They are fan-shaped and have tapered walls and thus readily permit the insertion or removal of the damper vanes when assembling.

The reduction of leakage to and from the outside of the chamber offered one of the most serious obstacles to the attainment of a high-efficiency damper. Each chamber is closed by a tight-fitting cover plate shown in Fig. 6, the only opening to the outside being a very small arc-shaped space left to permit the free travel of the arm, which carries the vane. By placing the chambers as near to the center as possible the size of this opening is reduced to a minimum, as is likewise the moment of inertia of the damper vanes.

Dr. Weston has denoted leakage to and from the outside as useless leakage, while that which takes place directly around the edges of the vane he has designated as useful leakage. By making the ratio of useful to useless leakage very high, the damping effect is brought under perfect control of the designer, who, by suitably dimensioning the clearance space between the vane and the walls of the chamber, can increase the damping action to any desired degree without adding an appreciable amount to either the weight or the moment of inertia of the movable system.

Pivots and Jewels

The system is supported by two highly polished cup-shaped sapphire jewels which engage two accurately ground and highly polished hardened steel pivots forced into holes in the sleeves on the extremities of the staff. The lower jewel is carried by a setting, that is forced into a hole in the hub of the base (Fig. 5), and the upper jewel is carried by a bearing screw which is threaded into a sleeve fastened rigidly to the bridge.

Jewel Adjustment

By means of the upper jewel-bearing screw the play between the pivots and jewels is adjusted, and once adjusted, the screw is locked in place by a simple and very excellent form of lock nut. As may be seen from Fig. 6, the lock nut is sawed half through across its axis and is provided with a small cap screw, which extends through the top across the slot and is tapped into the lower half. By tightening the cap screw the threads of the lock nut are pinched tightly about the jewel screw, thus preventing any possibility of its turning of its own accord. This method of locking the jewel screw is a distinct advance in instrument construction. It is a great improvement over the regular lock-nut method, which, due to lost motion, or backlash, is inherently imperfect. With the new locking device the backlash between the threads of the screw and the nut is practically eliminated by slightly tightening the cap screw just before the final adjustment is made, then, when all is ready, a slight turn of the cap screw clamps the jewel screw firmly without materially disturbing its adjustment.

A nice adjustment of the jewels is of great importance to the proper functioning of an instrument, and an otherwise excellent instrument can easily be rendered very inferior and its life greatly shortened by improper adjustment of its jewels. With the ordinary lock-nut method a good adjustment requires great skill and patience and the quality of the adjustment is apt to vary considerably with the workman; on the other hand, with this new method, accurate and uniform adjustments can be made with great dispatch and the danger of damaging a jewel by excess pressure is practically nil.

Two spiral springs attached with their outer ends to the fixed system and their inner ends to the movable system, serve the double purpose of opposing the electro-

Spiral Springs

magnetic torque and of connecting the terminals of the movable coil to the outside circuit. Like all springs used in Weston instruments, they are made of special alloy having characteristics which especially suit them for the particular service they are to perform. All springs, before being put into stock, are accurately gauged as to dimensions, their absolute force is measured and their elasticity is determined.

The inner ends of the spirals are inserted into forked tongues projecting from terminals carried on the upper end of the staff and connected electrically to the ends of the movable coil. The forks are pinched tightly around the spiral ends and are then soldered to give a perfect electrical connection. The outer ends of the spirals are attached to abutments fastened to the bridge.

The power-factor meter has no spring control. The spirals shown in Figs. 4 and 6 serve simply to connect the coils of the movable system to the external electric circuits and are designed to exert practically no torsional force. Their strength is just sufficient to render them self-supporting. To give an idea of the delicacy of these spirals, it may be said that 16,000 of them weigh only one ounce and the error due to torque produced by them is less than 1 per cent at only ⅕ load.

Bridge and Spring Abutments

The bridge which spans the space between the coil supports and carries the upper jewel and the spring abutments, consists of two similar metallic members insulated from each other and from the supports. The upper member carries one spring abutment and the upper jewel-bearing screw, while the lower one carries the other spring abutment.

The jewel-bearing screw is threaded into a sleeve permanently attached to the upper bridge member, and passes freely through a similar sleeve on the lower member. The upper spring abutment fits around the upper sleeve and is held tightly against a flanged portion of the sleeve by a spring washer inserted between the abutment ring and the bridge member. The lower abutment is fastened in a similar way to the sleeve on the lower member. It will be seen that by this construction the usually difficult task of effectively insulating the terminals of the movable coil from each other has been rendered comparatively simple and very effective, and that the precision of adjustment of the parts has been greatly increased.

The bridge members are accurately located with respect to the true axis of the system by the use of special flanged insulating sleeves which accurately fit cylindrical pins on the tops of the standards and also fit the bridge members and maintain a definite spacing between them. The precise location of these members is of great importance, and especially is this true of the upper member, which carries the jewel bearing.

Cap screws, which screw into the tops of the pins on the standards, serve to hold the bridge members firmly in place. Under each of these cap screws and between two insulating washers there is a terminal ring, which is connected to the spring abutments by a flat spring lead. These S-shaped flat springs are clearly shown in

Fig. 3. The purpose of this form of terminal connection is to provide a conductor which will retain its electrical resistance unaltered by the adjustment of the abutments, and which, at the same time, will not interfere with such adjustment.

The bridge construction and spring abutments of the power-factor meter differ considerably from the above described arrangement, as is immediately apparent from an inspection of Figs. 4 and 6. This bridge consists of only one member which serves simply to carry the upper jewel and maintain a rigid and accurate relation between the field-coil supports. The spiral springs are attached to rigid leads held firmly in place by the cap screws on the upper ends of the coil supports, which clamp them between ivory washers, as may be seen in the illustrations.

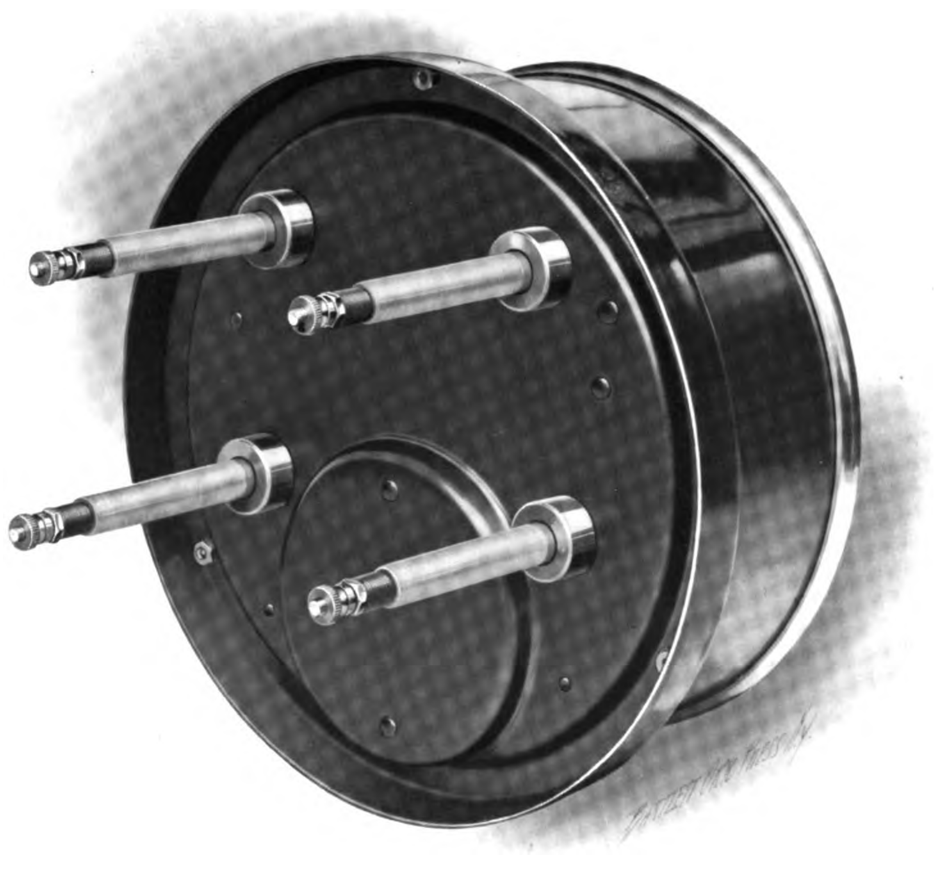

Fig. 9. Rear View of Model 167 Wattmeter

Zero Adjustment

The wattmeters and the soft-iron voltmeters and ammeters are all provided with a simple means of adjusting the pointer to the zero position on the scale, the adjustment being made with a screw-driver from the outside of the case. This improvement should be welcomed by the user, since even the best of instruments is liable to a slight shift of the pointer from its zero position, due to spring sag caused by rough handling during transportation.

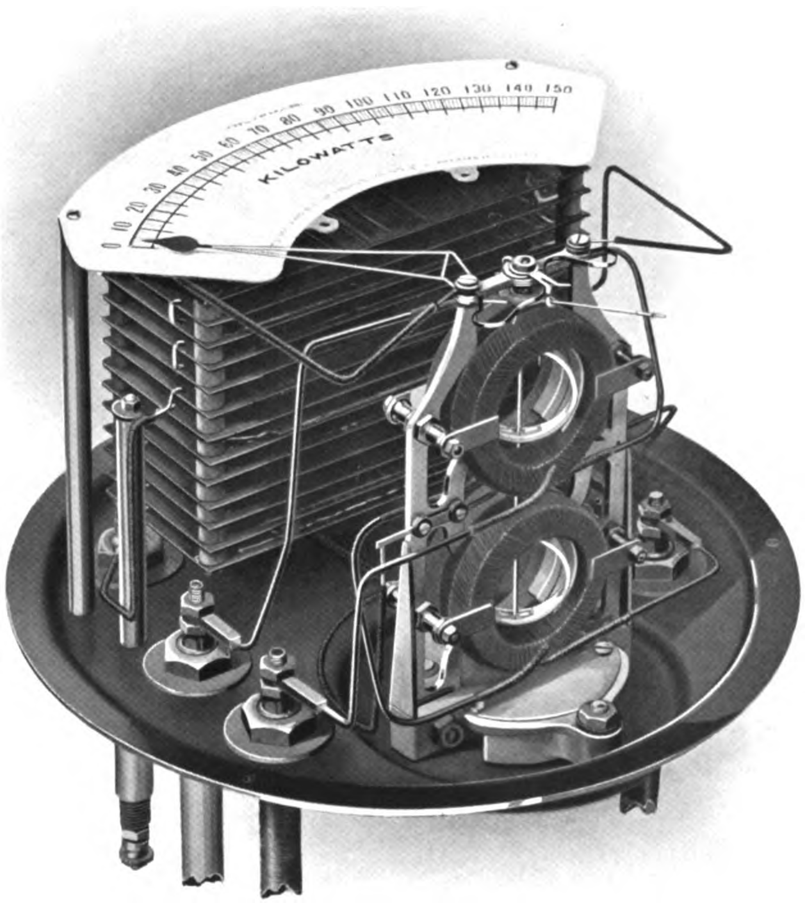

Fig. 10. Interior of Model 216 Wattmeter

This novel mode of adjustment is accomplished by providing the upper spring abutment with a radial arm, which terminates in a forked slotted opening, as shown in Fig. 3. A pin, which may be brought into engagement with this arm, is eccentrically located on a short block of insulating material carried by a stud in the cover of the instrument. The end of this stud is screw-slotted to receive a screw-driver.

The function of the forked ends of the slotted arm is to facilitate assembly and to prevent bending the abutment in case the cover is ever taken off and replaced. When assembling the instrument in the factory, the upper spring abutment is placed in the middle position; that is, with the slot in the radial arm in a diametral line. The lower adjustable spring abutment is then turned until the pointer comes to zero. The eccentric pin in the cover is next turned to its lowest position; that is, to the point furthest from the center of the instrument. Now the cover is put in place and fastened, and the eccentric pin is entirely without the range of the radial arm and cannot strike any part of the abutment. Inserting a screw driver into the screw-slotted stud, the eccentric pin is turned 90 deg., when it engages either one or the other of the branches of the fork. Further turning will displace the pointer from its zero position and also bring the pin into close engagement with the slot in the arm. Then continuing the turning of the stud, the pointer is brought back to zero when the eccentric pin is at the point nearest the center of the instrument. With the pin in this position the pointer can be turned an equal amount either to the right or left of the zero position by turning the stud a corresponding amount in one direction or the other.

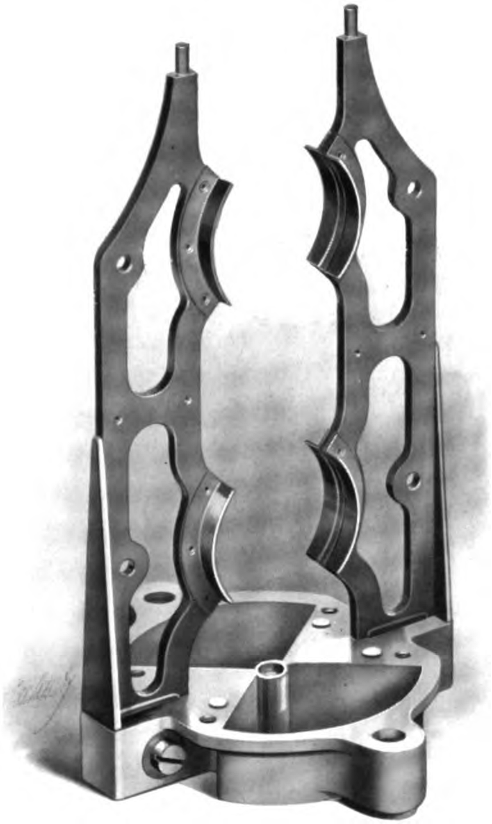

Fig. 11. Base and Coil Supports of Model 216 Wattmeter

With this device, therefore, a departure of the pointer from zero can be quickly remedied by anyone without breaking the seals of the instrument or incurring the slightest risk of damaging the movement.

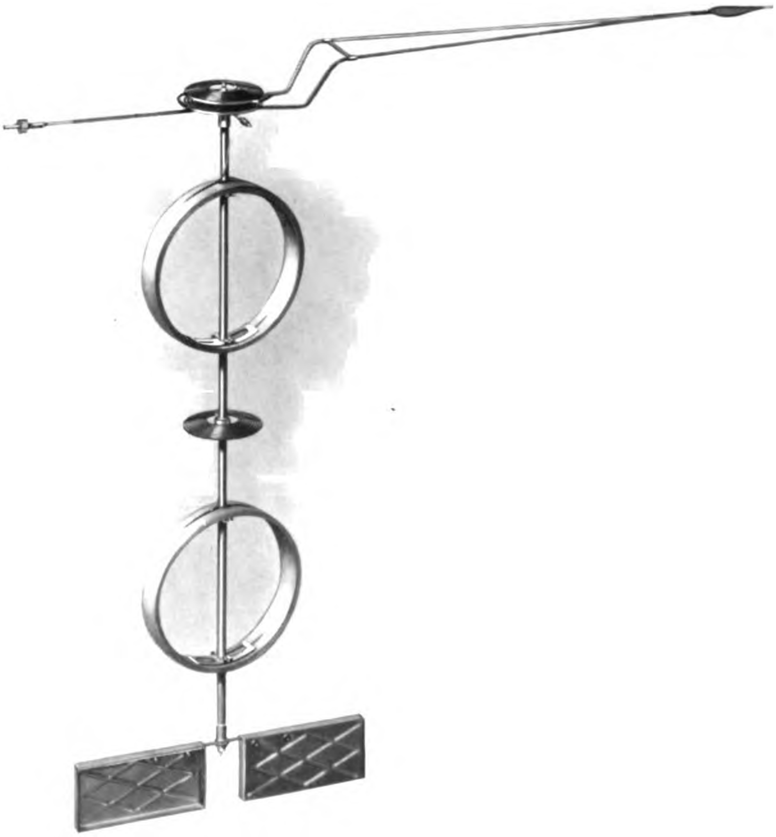

Fig. 12. Movable System of Model 216 Wattmeter

Case and Shielding

All these switchboard instruments are mounted in round pattern cases of the same design and of the same base and front dimensions, which simplifies the switchboard construction and gives the board a uniform and harmonious appearance. The polyphase wattmeter is mounted in a special semi-flush case in order to harmonize with the rest of the instruments in this group; however, it is also built with a full-front type case for mounting on the front of the board. The cases are of special steel and are made absolutely dust-proof. They effectively shield the instruments from any external magnetic fields which should ever be encountered in actual service. The exact amount of shielding provided by these cases is demonstrated by tests, the results of which are set forth in Section 3.

Fastening to Board

In all these instruments, except the semi-flush type polyphase wattmeter, the labor of mounting the instrument on the switchboard has been greatly reduced by the use of a novel mode of construction, and in no case is it necessary to drill more holes in the board than are required to bring the leads into the instrument. With the semi-flush type polyphase wattmeter the entire instrument, terminals and all projects through the back of the board. In the other instruments, where the terminals are large enough in themselves, they are utilized as bolts, and where they are too small for this purpose they are surrounded by wrought iron sleeves fastened to the back of the case, as shown in Fig. 9, and the instrument is held to the board by nuts screwed over these sleeves. These sleeves also serve another useful purpose; they enable the terminals to pass through iron structural work on the board without requiring the use of separate insulating sleeves, since the terminals are already thoroughly insulated and protected by the iron sleeves on the instrument. Furthermore, being conductively connected to the case, they may be used as terminals for the ground connection. The semi-flush polyphase wattmeter is provided with a special ground terminal.

Polyphase Wattmeters

The polyphase wattmeter consists of two single-phase movements mechanically coupled with the movable coils on the same staff. This double-deck type of construction, shown plainly in Fig. 10, requires some stiffening of the parts, but otherwise it is quite the same as used in the single-phase meters. The coil supports are stiffened by ribs along the lower outside edge, which give them sufficient strength without increasing their thickness and thus upsetting the coil proportions necessary to give uniform scale. The ribs are shown in Fig. 11. Fig. 12 shows the movable system of a three-phase wattmeter. A two-phase, four-wire movement would have two spiral springs in the middle instead of one, otherwise it would be the same.

So much for the purely structural side of these instruments. The commercial, or operating side, which pertains to their use and gives full information necessary for the guidance of purchasers, is treated in the following sections of this catalog. A separate section is devoted to each instrument, giving dimensions, ranges, prices, etc.

SECTION 3

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Weston Switchboard Indicating Wattmeters

THE efficiency of all energy transforming devices varies with the rate at which the transformation takes place; that is, boilers, engines, water-wheels, generators, motors, etc., in order to operate at maximum efficiency, must carry a certain definite load. In modern power plants the total equipment is usually divided into units, and the different parts of each unit should be so chosen as to give maximum possible economy at some certain load, and, therefore, there are definite limits of load between which any given group of units should be operated for maximum efficiency of the plant as a whole, and as soon as the load falls outside of these limits, a unit should either be thrown in or cut out of service, as the case may be; otherwise, the plant economy cannot be maintained at its maximum point.

Therefore, if a plant is to be run at its maximum efficiency, accurate knowledge of the value of the load, or power, must be available at all times.

Power Measurement

The electric power of a circuit is the rate at which work is done in that circuit. In direct-current circuits the power in watts equals the amperes, as measured with an ammeter connected in series with the circuit, multiplied by the volts, as measured with a voltmeter connected between the terminals of the circuit; that is,

$$\text{Watts} = \text{Amperes} \times \text{Volts}.$$

In alternating-current circuits, however, the power is not always equal to the product of amperes and volts as measured with an ammeter and voltmeter, but is usually considerably less. The product of effective amperes and effective volts as measured, respectively, with an ammeter and voltmeter is the *apparent power*, and the true power divided by the apparent power is called the *power-factor;* that is,

$$\text{Power-factor} = \frac{\text{Amperes} \times \text{Volts}}{\text{Watts}},$$

and

$$\text{Watts} = \text{Amperes} \times \text{Volts} \times \text{Power-factor}.$$

In both alternating-current and direct-current circuits the power is always equal to the instantaneous product of current and e. m. f., and the *average power* during a given interval is equal to the *average product* during that time. In direct-current circuits, the e. m. f. and current are constant for a given load and the product of the average current and the average e. m. f. is always equal to the average power. In alternating-current circuits the instantaneous value of the current and e. m. f varies continuously, irrespective of the load, and the average of each separately is zero, because half the time the current and e. m. f. are in one direction, and half the time they are in the

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Equation for power-factor should read:

$$\text{Power-factor} = \frac{\text{Watts}}{\text{Amperes} \times \text{Volts}},$$

true average power in watts, or kilowatts, regardless of changes in power-factor. Therefore, a properly designed and constructed wattmeter will give in *one indication* the product of the *effective current*, the *effective electromotive force* and the *power-factor*. Furthermore, the indications of such an instrument should be substantially unaffected by changes in load; that is, the accuracy should be the same with fluctuating load as with steady load.

From what has been said above it is evident that while the use of a good wattmeter is highly desirable for power measurements in direct-current circuits, it is actually imperative for accurate power measurements in alternating-current circuits. In fact, a good wattmeter is absolutely necessary to the economical operation of an alternating-current station.

Wattmeter Types

Whether an indicating wattmeter will properly perform the functions above set forth, depends in a large measure upon the type to which it belongs. Some types are inherently incapable of doing so; others do so only imperfectly. But even when the best type is selected, the degree of perfection with which a wattmeter of that type will conform to the requirements essential to the proper performance of its functions, under all the varied conditions of practical work, will depend greatly upon the scientific knowledge and skill of the designer, and upon the care and skill of the manufacturer. For, simple as the instrument itself may seem, the design and construction of a thoroughly reliable and durable instrument for the purpose specified, which will be capable of indicating accurately and continuously the true average power on alternating-current circuits under the widely differing conditions of frequency, power-factor and changes in load occurring in practical work is a most complex electrical and mechanical problem, the complete solution of which is a task of no mean order.

Quite a number of different types of wattmeters have been invented and many modified forms of the different types have been made and used to some extent. Most of the various types and modified forms of these types may be looked upon as scientific curiosities, because they have little or no practical utility. Others have some value in special work which may be considered as outside of the domain of engineering practice. With the exception of two types, the remainder are so inferior as to be unworthy of serious consideration as switchboard instruments.

Induction Type Wattmeter

The two types referred to above are the induction, or Ferraris type, and the indicating pivoted coil electrodynamometer, or Weston type. Dr. Weston has critically analysed the induction type and exhaustively studied the electrical and mechanical characteristics of the best commercial forms of it. The results of these investigations will form the subject of a later publication. Suffice it for the present to state that nothing was found to commend the type or to warrant the Weston Electrical Instrument Company in developing any form of it for sale. Indeed, the results of the investigations conclusively prove that there is no sound reason for the creation of the type and no justification for perpetuating it.

Weston Type Wattmeter

The designation of electrodynamometer type as the Weston type was done advisedly, and, as a matter of fact, the latter designation is much more appropriate than the former. First, as was pointed out in Section 2, Dr. Weston invented and developed the first indicating pivoted coil electrodynamometer instrument. Second, the term electrodynamometer as applied to wattmeters includes a number of different forms of wattmeters which possess radically different mechanical, electrical and operative characteristics from the type we are directly interested in. Indeed, the phrase necessarily includes every form of wattmeter in which the actuating force is directly and simply due to the magnetic fluxes developed by currents in fixed and movable coils, irrespective of the

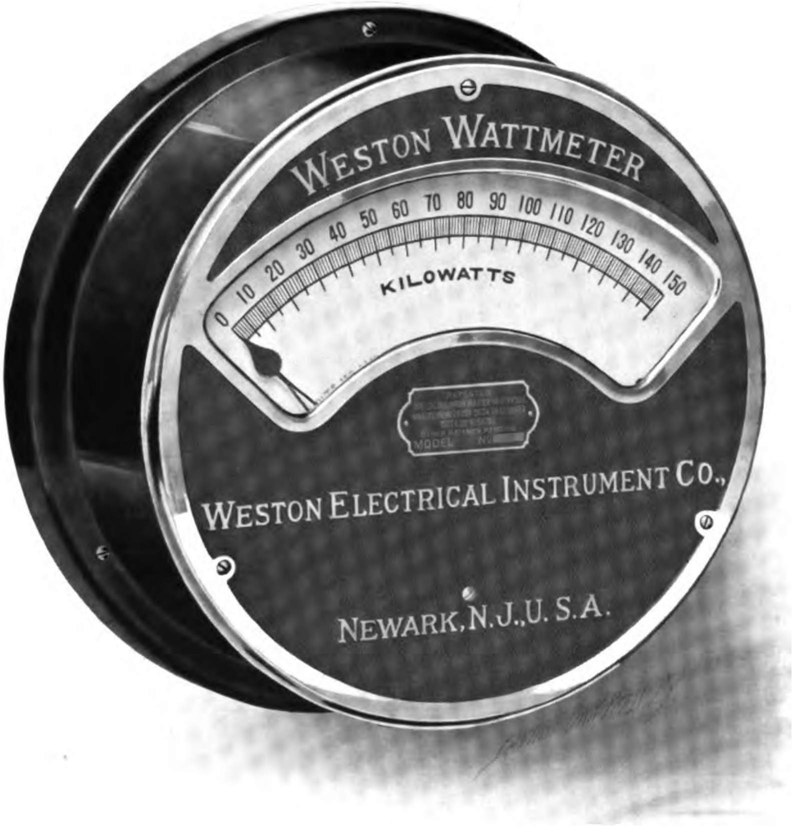

Fig. 14. Single-phase and Direct-current Wattmeter, Model 167

manner in which, or means by which, the magnitude of the force is determined or ascertained.

The type is also referred to as the precision wattmeter, and quite often it is designated by the name of a designer or maker of some form of it in which all the essential operative elements are the same or substantially the same as the original instrument of the Weston type, but in which the shape of the containing case is changed and the form and disposition of certain of the parts are changed to suit. Whatever name is given to it by other designers or makers, the main operative characteristics, serving to distinguish this type of wattmeter from all other preceding forms or types, are in all instances preserved. Moreover, in no instance has the original form, as a whole, been bettered by change in name or by change in shape and in the disposition or arrangement of its parts; indeed, the result has invariably been the reverse.

Early Weston Switchboard Wattmeters

As was pointed out in Section 2, the prototype of the present Weston wattmeter is an electrodynamometer voltmeter developed by Dr. Weston in the late eighties, his first patent being applied for in January, 1890. This was quickly followed by a portable wattmeter and later by a horizontal edgewise switchboard type, a patent on which was applied for in December, 1897.

The Weston portable wattmeter is well known; it has been of inestimable value in the development of alternating-current engineering practice and is universally recognized as the best wattmeter on the market to-day.

Horizontal Edgewise Wattmeters

The Weston horizontal edgewise switchboard wattmeter is described in Section 2 of this catalog. The horizontal edgewise arrangement was adopted to avoid friction at the pivots, which is a serious obstacle to the production of a thoroughly useful electrodynamometer wattmeter. Although by use of this expedient in conjunction with an effective oil damper, an accurate, reliable and durable instrument was produced, it was never officially placed on the market. The reason for this action on the part of the Weston Electrical Instrument Company, was its unwillingness to accept the horizontal edgewise type as the final solution of the switchboard wattmeter problem. However, the Company has made and sold a large number of these horizontal edgewise wattmeters and voltmeters, and many are now in use.

The horizontal edgewise instrument saves a slight amount of vertical space on the switchboard; however, this saving in space is more than offset by decreased accuracy and by difficulty of reading. A horizontal edgewise scale can be read only from a position directly in front of the pointer. In fact, if the pointer is near that end of the scale farthest from the observer it is often entirely invisible. Furthermore, the curved glass cover has the disagreeable characteristic of reflecting strong lights in such a manner that considerable manoeuvring is often necessary in order to see the scale and sometimes even the pointer. In most cases the reason for limiting the size of a switchboard is to permit its operation by a minimum number of attendants, and in this respect the horizontal edgewise arrangement is a flat failure. For, as a matter of fact, it actually increases the labor of attendance, and results in one of two things, namely: more attendants are required to do the work; or, the accuracy of the indications and therewith the usefulness of the instruments must be sacrificed.

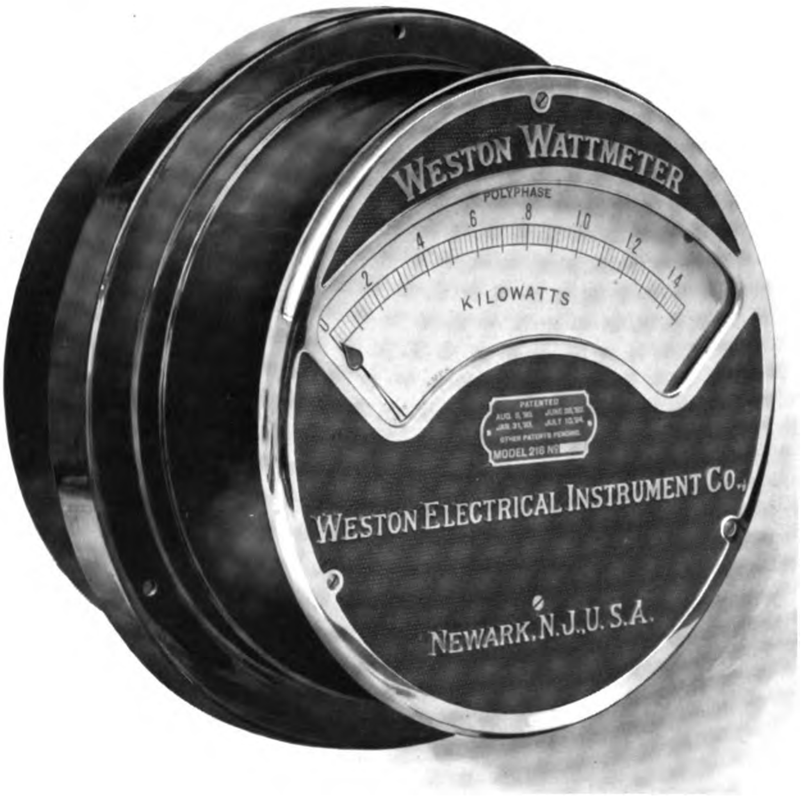

Fig. 15. Polyphase Wattmeter, Model 216, Semi-flush Case

Weston Switchboard Wattmeters

In the present type of Weston switchboard wattmeter, by intelligent design and skillful construction, every heretofore existing difficulty has been satisfactorily overcome and the results attained with these instruments are far in advance of anything ever accomplished in the art of commercial electrical measurement.

The construction of these wattmeters is described in great detail in Section 2 of this catalog. In the present section, we shall confine our remarks to purely commercial data such as operating characteristics, dimensions, ranges, prices, etc.

Unique Operative Characteristics

The electrical and mechanical characteristics of these wattmeters are unique as regards the high standard of perfection attained. Every one of the factors which have hitherto limited the usefulness of such instruments, has been so far reduced as practically to eliminate its influence within the range of conditions existing in commercial practice. In order to bring out more forcibly the extent and importance of the improvements embodied in these new wattmeters, a list of some of their operative advantages is given below:

1. The scale is uniform throughout the entire range of deflection.
2. The readings can be made with practically the same precision on violently fluctuating loads as on steady loads.
3. The indications are equally accurate on direct-current circuits or on alternating-current circuits of any frequency, power-factor or wave form within commercial limits. Therefore, these wattmeters can be calibrated with direct current and used on alternating-current circuits without change of calibration.
4. The scale is flat and is therefore easily read.
5. The movable system is entirely free of mechanical resonance.
6. The power consumption is extremely small.
7. They have a large overload capacity, which will allow the measurement of full power at power-factors below 0.50.
8. They are far more reliable and durable than any commercial wattmeter heretofore built.
9. They are accurate within the limits of scale reading, regardless of changes in temperature, frequency, power-factor and wave form, within the range of commercial practice.
10. The zero position of the pointer can be adjusted from the outside without removing the instrument from the board.

In order to bring out the true importance of these advantages and the actual limits of accuracy of the instrument under the various conditions of commercial practice, we will now take up some of the operative factors in the order listed above, and discuss them more fully.

Uniform Scale

This is the first and only electrodynamometer switchboard wattmeter to have a uniform scale throughout its entire range of deflection. Indeed, a non-uniform and purely empirical scale had become universally accepted as a necessary evil, inherent to this type of instrument. A uniform scale is especially desirable in switchboard instruments, since it permits the making of readings from a distance based on the general position of the pointer with reference to the scale as a whole.

On commercial circuits the load is continually changing in value, and a wattmeter that cannot follow the changes without a serious sacrifice in the accuracy and facility of reading its indications will be of little help in the economical operation of a plant.

The requirements of an instrument which can measure with practically the same accuracy on fluctuating loads as on steady loads, were set forth in Section 1 of this catalog, and the construction by means of which these requirements have been met is described in Section 2.

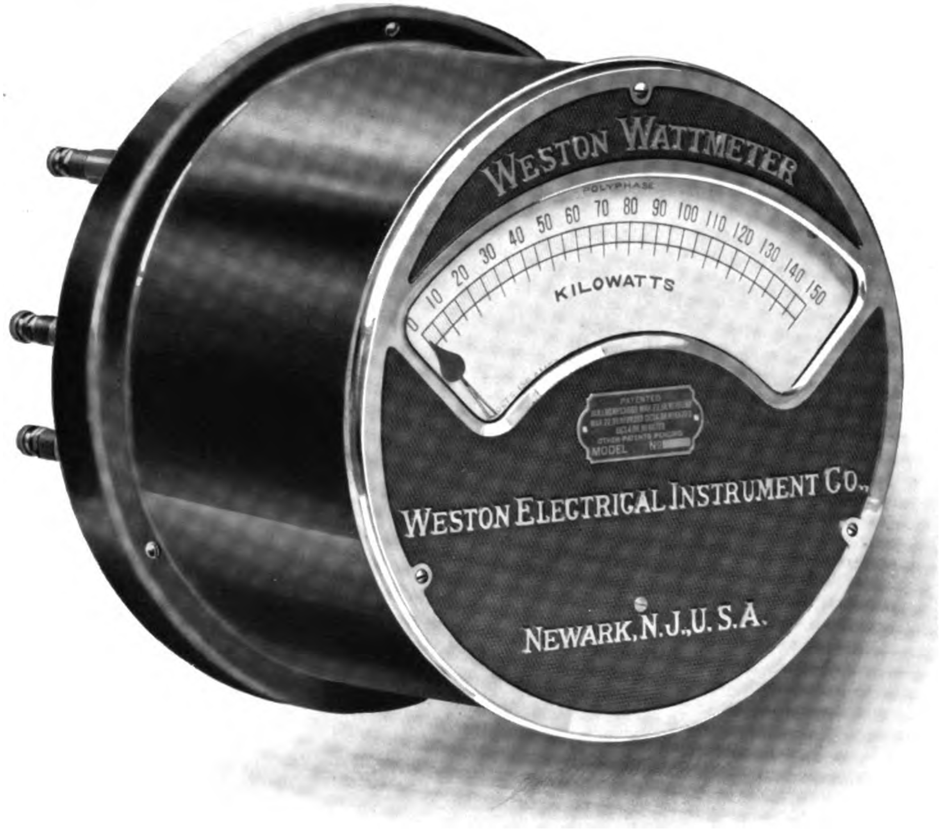

Fig. 16. Polyphase Wattmeter, Model 216, Full-front Case

Readings on Fluctuating Loads

The fact is, that by skillful design and exquisite construction, the Weston switchboard wattmeters have been rendered capable of following closely any variation in load and may be read with practically the same accuracy quite independent of whether the load is fluctuating or steady. The degree of this attainment is brought out very strikingly by the following tests: A sudden application of full load from a condition of no load produced a total over-swing of only two scale divisions. Fig. 17 shows the result of such a test, the numbers indicating the successive positions of the pointer. In this test, which is the most severe that can be applied to an instrument, it took the pointer just two seconds to come to perfect rest. A similar test on an ordinary instrument would have caused a violent collision with the stop and probably have wrecked the instrument.

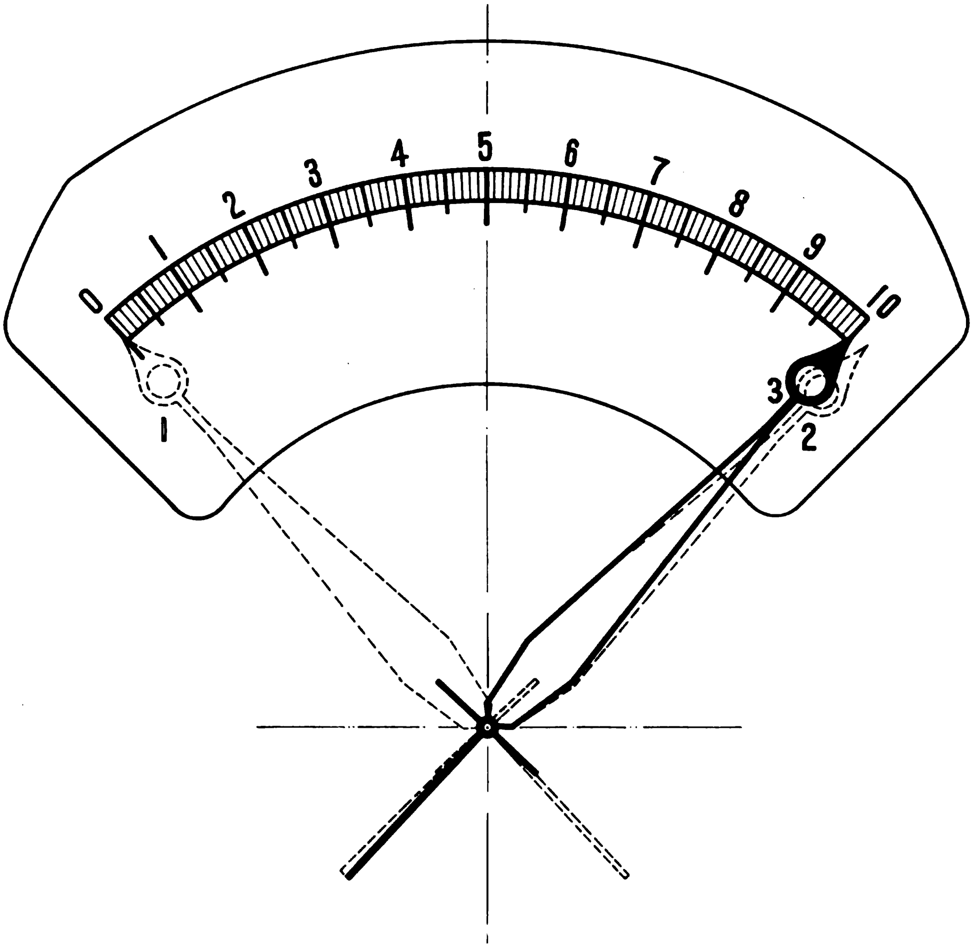

Fig. 17. Damping Test with Single-phase Wattmeter, Model 167

A comparative test between a Weston wattmeter and a well-known make of induction wattmeter, with half load applied under the same conditions gave the following results:

Type of Wattmeter	Weston	Induction
Over swing, per cent	3.0	65.0
Time to come to rest, seconds	1.5	6.3

NOTE—The Weston wattmeter could easily be made absolutely dead beat, and would be made so, were it not for the fact that a slight overswing is necessary to show that the movable system is free from friction.

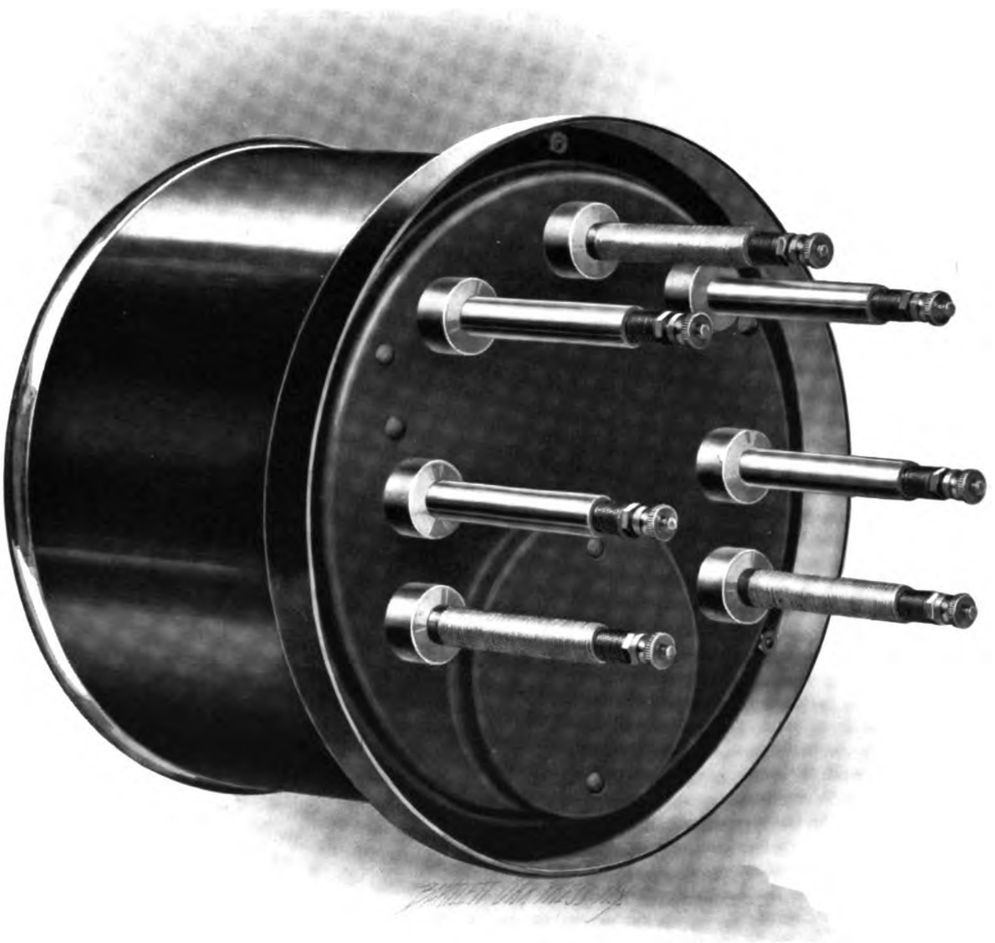

Fig. 18. Rear View of Full-front Polyphase Wattmeter, Model 216

Flat Scale

The various disadvantages of a curved scale were pointed out in the first part of this section, in connection with the description of the Weston horizontal edgewise wattmeter. In the present wattmeters, friction has been practically eliminated by an enormous reduction in the weight of the movable system, and therefore these instruments can be used with equal accuracy in any position, and the flat scale thus becomes perfectly feasible. The flat scale, in conjunction with the uniform or proportional scale characteristic of these wattmeters, enables the attendant to keep himself informed as to the value of the load without leaving his chair, except when he wants to make very accurate readings.

Resonant Vibration

It is well known that the working force in alternating-current instruments alternates in direction at such a high frequency that the movable system is unable to follow it, but takes up a position where the counter torque of the springs just balances the resultant or average torque of the working force. However, if the natural frequency of the movable system or any part thereof be a multiple of the frequency of the force, resonant vibration will be established. This phenomenon is extremely common in practice, since instrument designers seem to have entirely overlooked this exceedingly troublesome source of error, as is evidenced by the fact that the movable systems in most instruments have a natural period which falls within the limits of commercial frequencies. Indeed, if often happens that a pointer is set into violent oscillation by even slight departures from the frequency at which it was adjusted, and usually such oscillations are assumed to be due to fluctuations in the load.

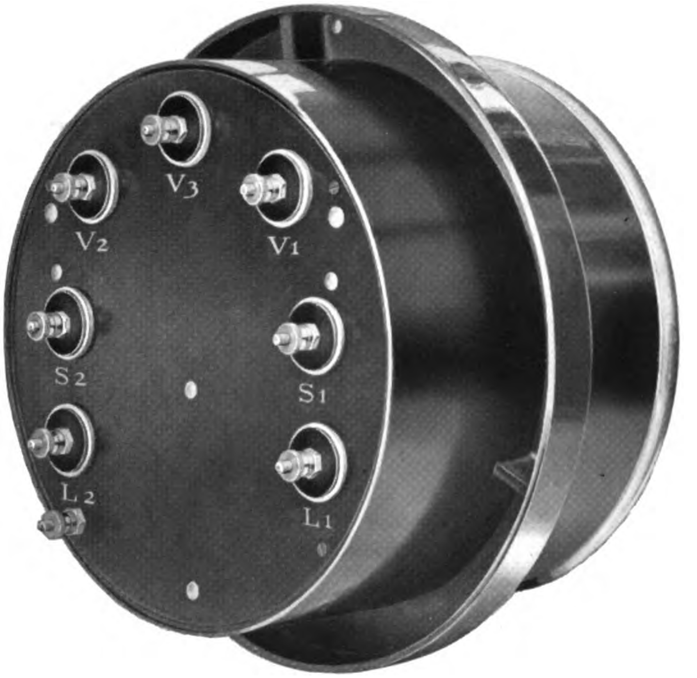

Fig. 19. Rear View of Semi-flush Polyphase Wattmeter, Model 216

With Weston wattmeters there is nothing to be feared from disturbances of this kind; actual tests at frequencies ranging frcm 15 to 900 cycles per second show that these wattmeters have no resonant point at any commercial frequency between these limits.

Power Consumption

The power consumption is negligible. The potential, or shunt, circuit at 110 volts requires less than 3.0 watts and the series, or current, circuit consumes only 0.75 watt at full load. The potential coil is connected on the line side of the instrument, therefore the potential loss is entirely eliminated from the indications and thus the error due to power consumed by the instrument is exceedingly small. The subject of energy loss in switchboard instruments seldom receives any serious consideration from the station engineer, and not a few would hotly dispute the fact that considerable money saving could be brought about by using one kind of instrument in preference to another. Nevertheless, it is a fact that some of the largest and most important stations in this country are needlessly losing large amounts of energy in their switchboard instruments every year.

Overload

The series coils are designed to carry double full-load current continuously, and will even stand three times full-load current without overheating. Therefore, these instruments can be used to measure full power at power-factors below 0.50.

Durability

The question of durability being of equal importance in all instruments, was treated in the introduction, Section 1. It was there shown that durability and reliability depend almost entirely upon the weight on the pivots and the amount of motion of the movable system. Therefore, it may be of interest to compare the weight of the movable system of a single-phase Weston wattmeter with that of two wattmeters of other make now on the market.

Type of Wattmeter	Weston	Other Makes	
		Electro-dynamometer	Induction
Weight of movable system, grams	1.84†	15.35*†	14.6
Weight on pivots, grams	0.92	15.35	7.3

*Horizontal edgewise type; therefore, all weight is on one pivot.

†These weights include the weight of the springs, which are in part self-supporting and thus do not add their whole weight to the load on the jewels.

Accuracy

The indicating wattmeter furnishes information which determines the number of units necessary to carry the load; it also serves as a guide for steam pressure adjustment; therefore, any discrepancy in the accuracy of its indications must necessarily be reflected in the cost of plant operation and maintenance. Many cheap and inferior instruments will show up well in tests made under specified conditions and when they are new. Weston instruments are built to give accurate results under actual service conditions and to remain accurate throughout a long period of years. The magnitude of the various errors is given in the following paragraphs.

There is no discernible error due to the heating effect of the current through the windings; therefore the indications are independent of the length of time the instrument is in circuit. A change in room temperature of 50 deg. fahr. (28 deg. cent.) either above or below the temperature at which the instrument was calibrated will produce an error of less than 1 per cent.

Temperature

Errors due to inductance of the windings and to eddy currents in the metallic masses vary with the frequency of the supply system. However, these errors have been reduced to such extremely low values that no perceptible error is caused by changes in frequency. Actual tests over a range of from 15 to 900 cycles per second showed a total error of only about 1 per cent even at power-factors as low as 0.50.

Frequency

The phase-angle error due to the inductance of the potential circuit varies with the range, but in all sizes it is negligible in any practical work. For the 5-amp. range single-phase wattmeter at 60 cycles, it is 1.2 min. angle. The nearest approach to this by any other make of switchboard wattmeter of the same range is 4.3 min., while another well known make has a phase angle of 6.7 min.

Phase Angle

One of the most remarkable achievements embodied in these wattmeters is their freedom from eddy currents. Eddy-current errors vary with the power-factor, and therefore cannot be satisfactorily compensated. The only way to eliminate the error is to avoid eddy currents. The total eddy-current error in these wattmeters has been reduced to such a degree as not to be discernible on the scale.

Eddy Currents

The steel case shields the movement from the action of external fields. When used on alternating-current circuits direct-currents have no effect whatever on the indications of these instruments. A conductor carrying 700 amp. at the same frequency as that of the system to which the instrument is connected, may be placed within 3 ft. of the meter without causing an error greater than 1 per cent, and if two conductors of the same circuit are placed 1 ft. apart and at the same distance from the wattmeter 2800 amp. may be carried without producing an error as great as 1 per cent.

Shielding

Spring sag caused by shocks due to rough handling during transportation often causes the pointer to depart from the zero position, and its readjustment must ordinarily be entrusted to a skilled instrument mechanic. The Weston wattmeters are equipped with a special device by means of which the pointer may be brought to its zero position from the outside of the case. This adjustment is made with a screw driver from the front and does not require the instrument to be removed from the board nor the breaking of any seals. Furthermore, any one can make the adjustment, as it is absolutely impossible to damage the instrument by any misuse of the device.

Zero Adjustment

These wattmeters are made in two models: Model 167 for single-phase circuits, and Model 216 for polyphase circuits, and both models are regularly carried in 41 different ranges as shown by the fac-simile scales which are reproduced in Figs. 30 and 31. Both these models are made in ranges which may be connected directly to the line for potentials up to 750 volts; above this, potential transformers are used. The series coils are made in sizes for direct connection up to 100 amp. carrying capacity and above this current transformers must be used. For voltages above 750 both potential and current transformers are always used. See the tables at the end of this section for detailed list of ranges.

Models

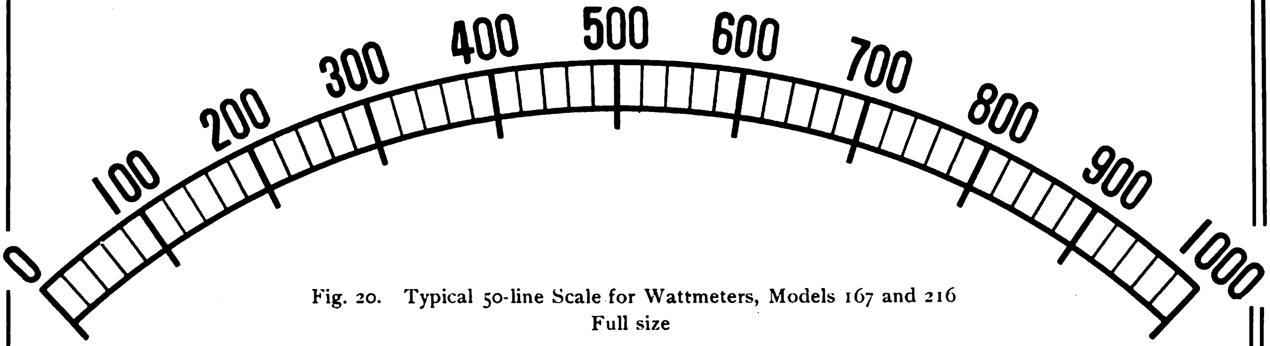

Fig. 20. Typical 50-line Scale for Wattmeters, Models 167 and 216
Full size

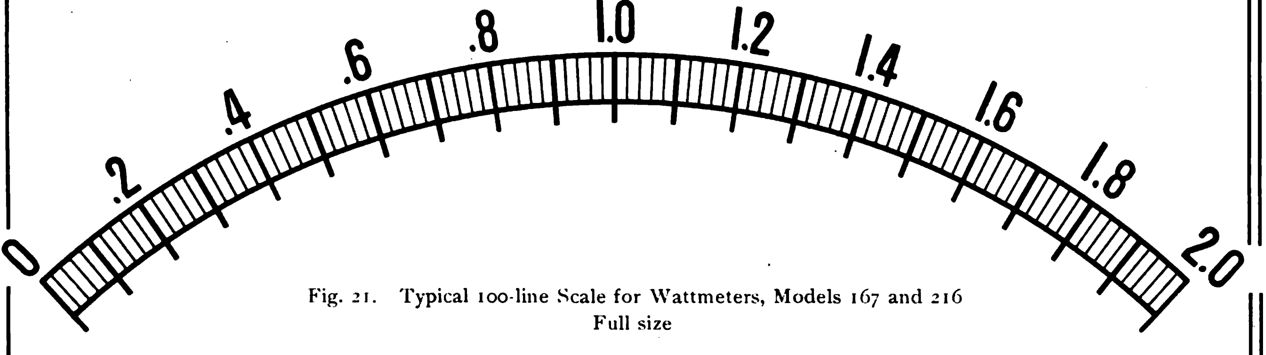

Fig. 21. Typical 100-line Scale for Wattmeters, Models 167 and 216
Full size

The cases are of the round pattern and have the same base and front dimensions as all the other electrodynamometer instruments in this group. They are absolutely dust-proof. The Model 216 polyphase wattmeter is regularly built with two styles of case, the full-front type (see Figs. 16 and 18) and the semi-flush type (see Figs. 15 and 19). The semi-flush type projects through the front of the board just far enough to be in the same plane with the other instruments of this group, and thus harmonizes with them. The full-front type of case is somewhat easier to install on the board and there is no objection to using it on isolated panels when it does not

Cases

appear side by side with shallower instruments. Both models may also be had in full-flush cases for use on bench boards; however, these cases are not recommended for general work on account of the cutting away of the board.

Terminals

In Model 167 wattmeters and the full-front type Model 216 wattmeters for current ranges below 20 amp., the leads are brought into the back through wrought-iron sleeves secured to the base, and the instrument is fastened to the board by nuts screwed over the sleeves. In meters for current ranges above 20 amp., the series terminals are sufficiently large to be utilized directly for securing the instrument to the board. With the semi-flush type, Model 216, polyphase wattmeters, the entire instrument, terminals and all, projects through the board, as shown in Fig. 19.

The wrought-iron sleeves shown in Fig. 18, in addition to supporting the instrument, also serve to insulate and protect the terminals. Protected by these sleeves the terminals may pass directly through structural iron work on the board without any fear of grounding. Furthermore, these sleeves, being conductively connected to the case, may be used for the ground terminal. The semi-flush Model 216 wattmeter, not having sleeves, is equipped with a special terminal for grounding the case, as shown clearly in Fig. 19.

Price List of Model 167 D. C. and Single-phase Wattmeters

Rating			Code Word	List Price	Rating			Code Word	List Price
Volts	Amperes	Scale			Volts	Amperes	Scale		
100 to 150 Self-contained	1	150 watts	Siph	$50.00	400 to 600 External Resistor	1	600 watts	Singwat	$61.00
	2	300 watts	Siphwon	50.00		2	1.2 kw.	Singphe	61.00
	5	500 watts	Sipwat	50.00		5	2 kw.	Singphat	61.00
	5	750 watts	Sipher	50.00		5	3 kw.	Singphur	61.00
	10	1 kw.	Siplow	50.00		10	4 kw.	Sinphul	61.00
	10	1.5 kw.	Sipper	50.00		10	6 kw.	Siphat	61.00
	20	2 kw.	Siphon	50.00		20	8 kw.	Siphzer	61.00
	20	3 kw.	Singpa	50.00		20	12 kw.	Siphtum	61.00
	50	5 kw.	Singphon	50.00		50	20 kw.	Siphgut	61.00
	50	7.5 kw.	Siping	50.00		50	30 kw.	Siphurt	61.00
	100	10 kw.	Sipear	56.00		100	40 kw.	Siphest	67.00
	100	15 kw.	Sipluf	56.00		100	60 kw.	Siphnur	67.00
200 to 300 Self-contained	1	300 watts	Siphle	56.00	600 to 750 External Resistor	1	750 watts	Siphburn	67.00
	2	600 watts	Sipul	56.00		2	1.5 kw.	Siphbat	67.00
	5	1 kw.	Sipale	56.00		5	2.5 kw.	Siphtal	67.00
	5	1.5 kw.	Siplum	56.00		5	4 kw.	Sigphas	67.00
	10	2 kw.	Sipmer	56.00		10	5 kw.	Sighug	67.00
	10	3 kw.	Sipcug	56.00		10	7.5 kw.	Sigpult	67.00
	20	4 kw.	Sipgam	56.00		20	10 kw.	Sigfant	67.00
	20	6 kw.	Sippit	56 00		20	15 kw.	Siglam	67.00
	20	7.5 kw.	Siphim	56.00		50	25 kw.	Sigphal	67.00
	50	10 kw.	Sipant	56.00		50	40 kw.	Sigphlit	67.00
	50	15 kw.	Sipalg	56.00		100	50 kw.	Sigfus	75.00
	100	20 kw.	Sipgun	61.00		100	75 kw.	Sigphish	75.00
	100	30 kw.	Sipleg	61.00					

NOTE—Higher ranges may be had by using transformers. We recommend the 5-amp. range instruments for use with current transformers. Prices of these wattmeters in full-flush cases will be furnished upon application.

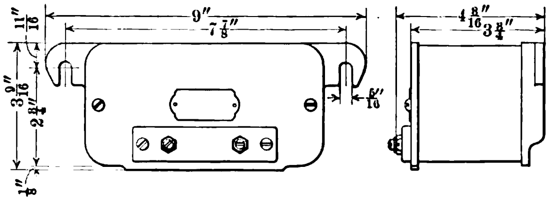

Fig. 22. Dimensions of Box for External Resistor for Model 167 Wattmeter

Price List of Model 216 Polyphase Wattmeters

Full-front and Semi-flush Type

Rating			Code Word	List Price	Rating			Code Word	List Price
Volts	Amperes	Scale Kilowatts			Volts	Amperes	Scale Kilowatts		
100 to 150 Self-contained	5	1	Phwat	$70.00	400 to 600 External Resistor	5	4	Polyun	$80.00
	5	1.5	Polwat	70.00		5	6	Polyput	80.00
	10	2	Polyphat	70.00		10	8	Polykink	80.00
	10	3	Polacy	70.00		10	12	Polykur	80.00
	20	4	Polwack	70.00		20	20	Polyken	80.00
	20	6	Poluse	70.00		20	30	Polyche	80.00
	20	7.5	Polwon	70.00		50	40	Polycros	80.00
	50	10	Polwish	70.00		50	60	Polykne	80.00
	50	15	Poly	70.00		100	80	Polykit	85.00
	100	20	Polyphun	75.00		100	120	Polykic	85.00
	100	30	Polyglot	75.00					
200 to 300 Self-contained	5	2	Polywat	75.00	600 to 750 External Resistor	5	5	Polysent	85.00
	5	3	Polytur	75.00		5	7.5	Polysis	85.00
	10	4	Polymet	75.00		10	10	Polysup	85.00
	10	6	Polmeter	75.00		10	15	Polsweet	85.00
	20	8	Poltem	75.00		20	20	Pols art	85.00
	20	12	Polturn	75.00		20	30	Pols nk	85.00
	50	20	Poltace	75.00		50	50	Pols ut	85.00
	50	30	Poltic	75.00		50	75	Polspank	85.00
	100	40	Poltup	80.00		100	100	Po',broke	90.00
	100	60	Polume	80.00		100	150	Polywise	90.00

NOTE—Higher ranges may be had by using transformers. We recommend the 5-amp. range instruments for use with current transformers. Prices of these wattmeters in full-flush cases will be furnished upon request.

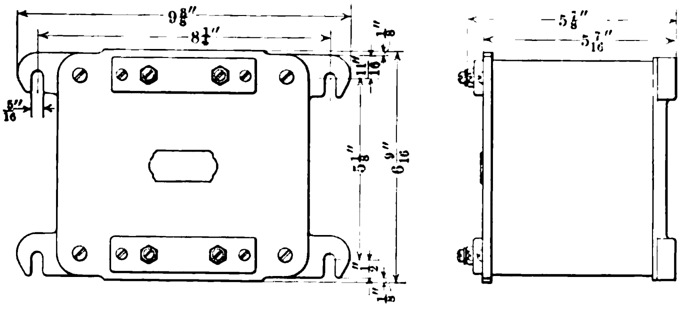

Fig. 23. Dimensions of Box for External Resistor for Use with Model 216 Wattmeter

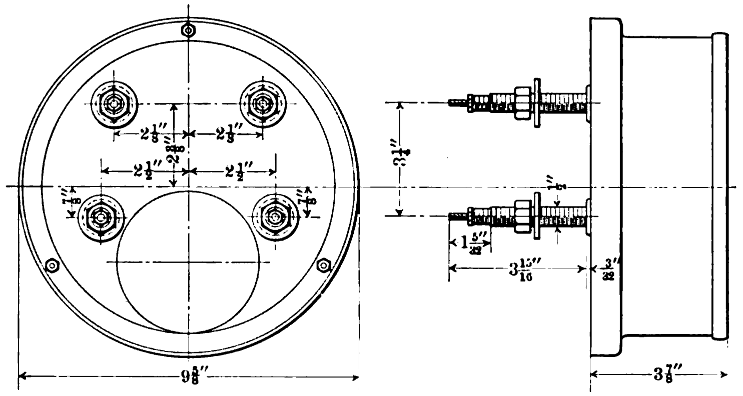

Fig. 24. Dimensions of Model 167 D. C. and Single-phase Wattmeter, Range 1 to 20 Amp.

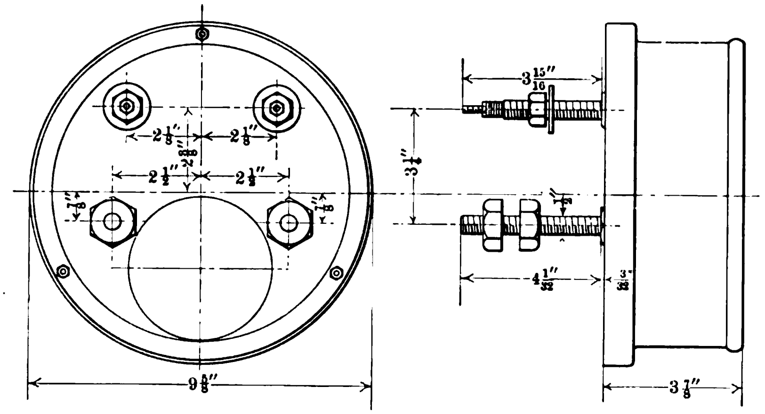

Fig. 25. Dimensions of Model 167 D. C. and Single-phase Wattmeter, Range 50 to 100 Amp.

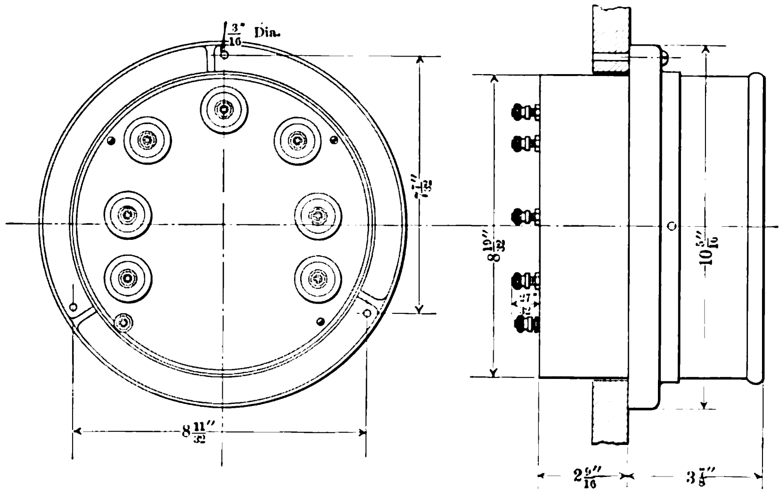

Fig. 26. Dimensions of Model 216 Semi-flush, Three-phase Wattmeter, Range 5 to 20 Amp.

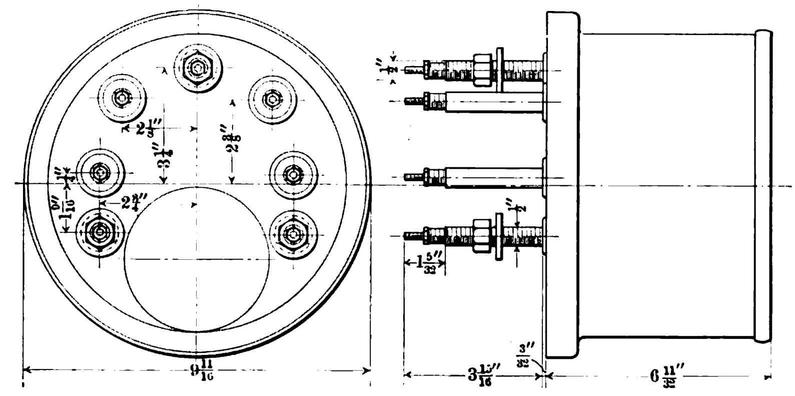

Fig. 27. Dimensions of Model 216 Full-front, Three-phase Wattmeter, Range 5 to 20 Amp.

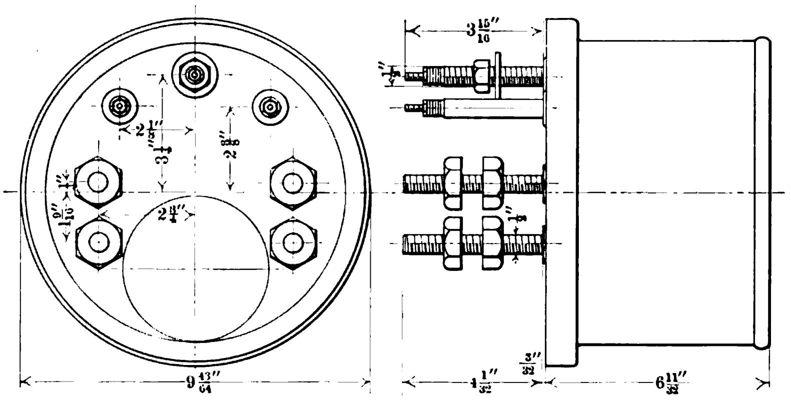

Fig. 28. Dimensions of Model 216 Full-front, Three-phase Wattmeter, Range 50 to 100 Amp.

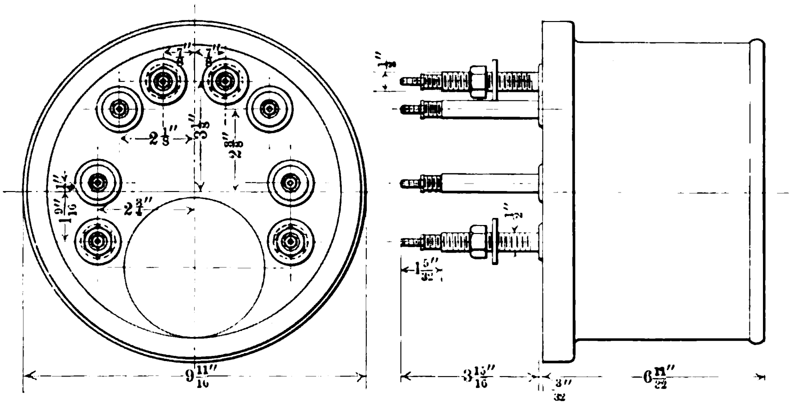

Fig. 29. Dimensions of Model 216 Two-phase, Four-wire Wattmeter, Range 5 to 20 Amp.

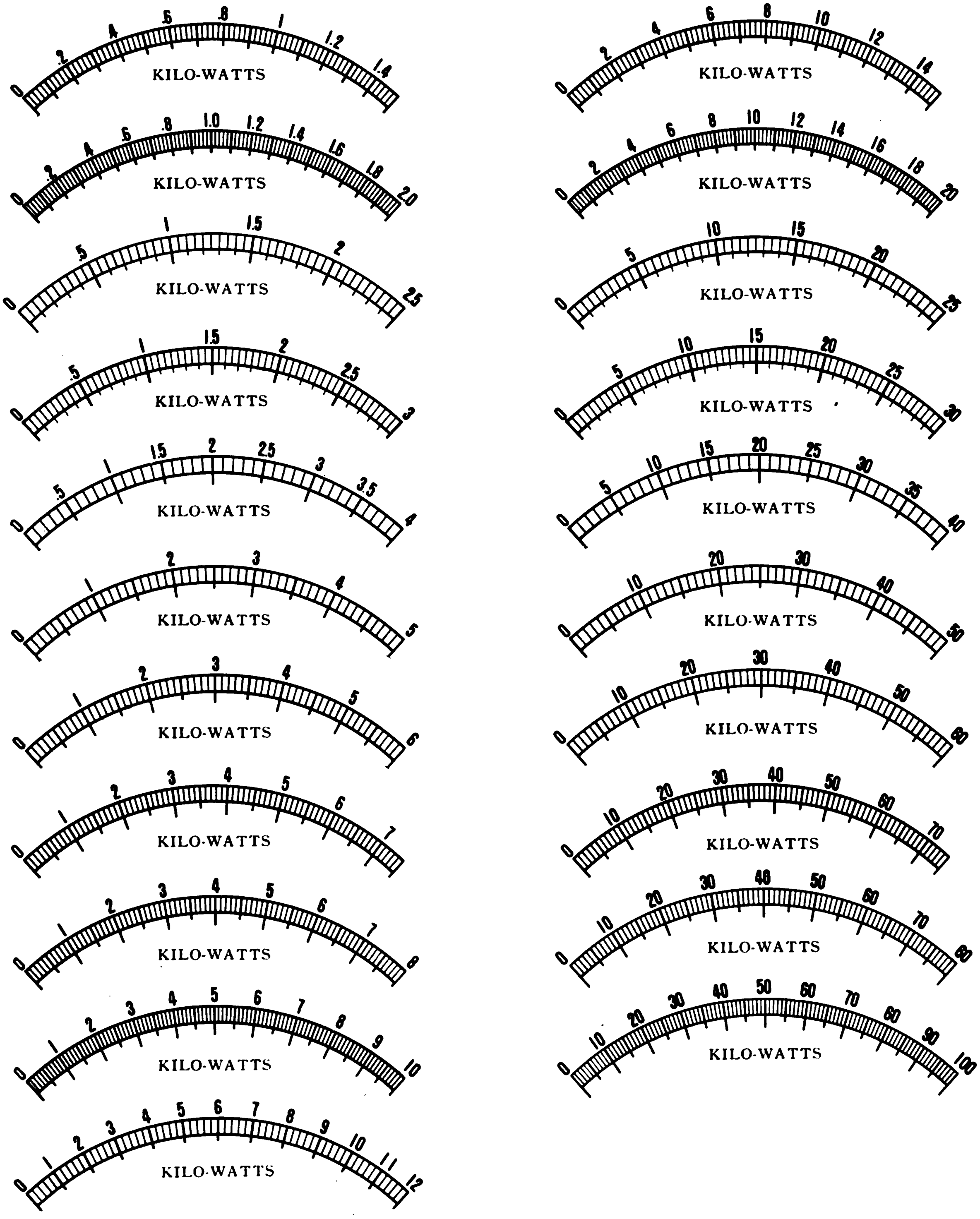
0 .2 .4 .6 .8 1 1.2 1.4 KILO-WATTS
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 KILO-WATTS
0 .5 1 1.5 2 2.5 KILO-WATTS
0 .5 1 1.5 2 2.5 3 KILO-WATTS
0 .5 1 1.5 2 2.5 3 3.5 4 KILO-WATTS
0 1 2 3 4 5 KILO-WATTS
0 1 2 3 4 5 6 KILO-WATTS
0 1 2 3 4 5 6 7 KILO-WATTS
0 1 2 3 4 5 6 7 8 KILO-WATTS
0 1 2 3 4 5 6 7 8 9 10 KILO-WATTS
0 1 2 3 4 5 6 7 8 9 10 11 12 KILO-WATTS
0 2 4 6 8 10 12 14 KILO-WATTS
0 2 4 6 8 10 12 14 16 18 20 KILO-WATTS
0 5 10 15 20 25 KILO-WATTS
0 5 10 15 20 25 30 KILO-WATTS
0 5 10 15 20 25 30 35 40 KILO-WATTS
0 10 20 30 40 50 KILO-WATTS
0 10 20 30 40 50 60 KILO-WATTS
0 10 20 30 40 50 60 70 KILO-WATTS
0 10 20 30 40 50 60 70 80 KILO-WATTS
0 10 20 30 40 50 60 70 80 90 100 KILO-WATTS

Fig. 30. Standard Scales for Single-phase and Polyphase Wattmeters. Reduced Size. These Ranges may be Extended Indefinitely by adding Ciphers to the Figures

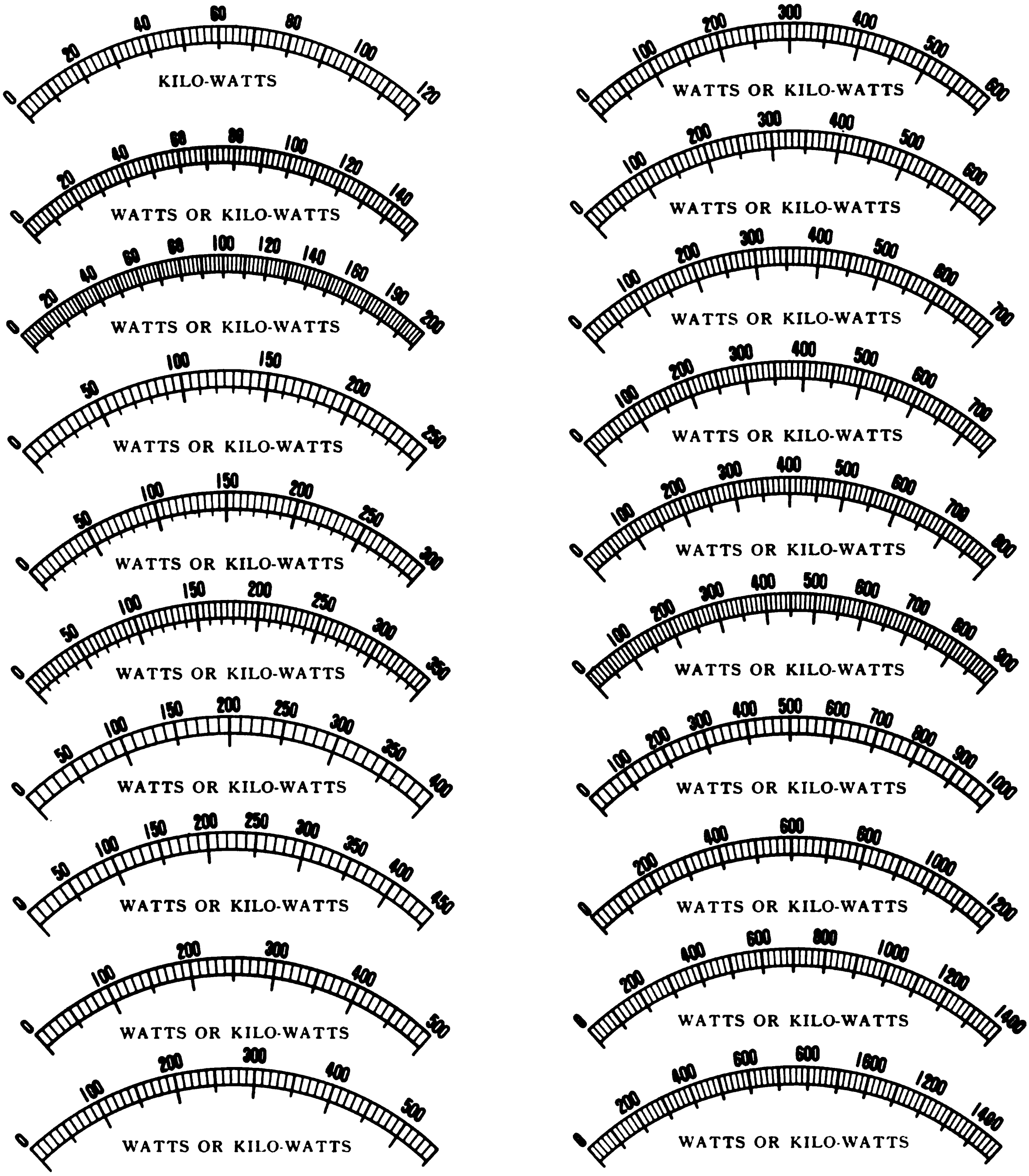

Fig. 31. Standard Scales for Single-phase and Polyphase Wattmeters. Reduced Size. These Ranges may be Extended Indefinitely by adding Ciphers to the Figures

SECTION 4

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Weston Synchroscope

WHEN two machines generate e. m. fs. of the same value and frequency, and coincident in time-phase, they are said to be in synchronism. When synchronous machines, such as synchronous generators, motors and converters, are operated in parallel, they must be in synchronism, and any tendency to depart therefrom will call forth corrective currents of the proper phase and magnitude to restore the synchronous condition.

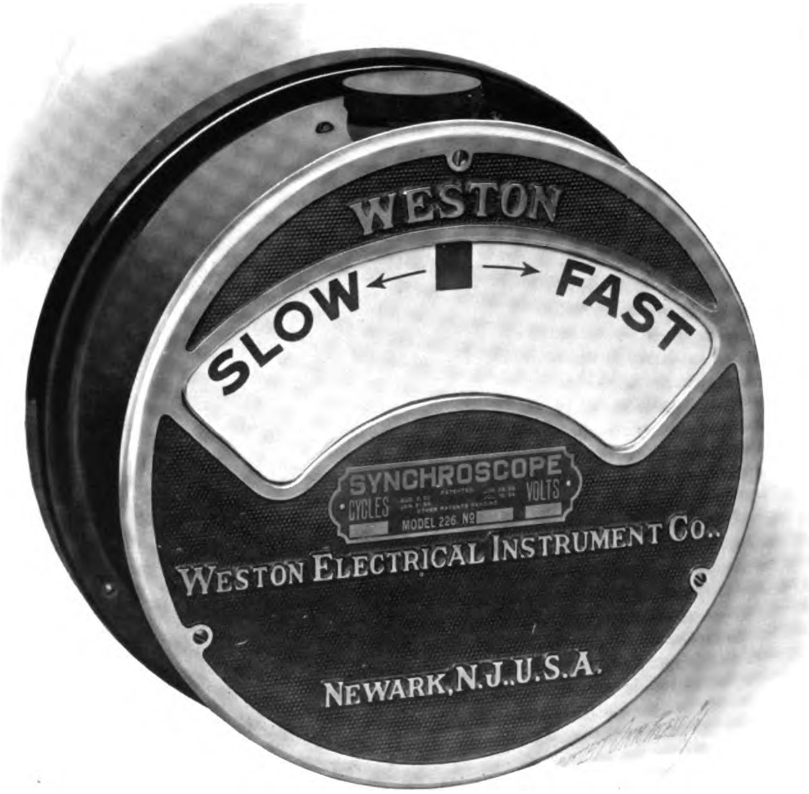

Fig. 32. Model 226 Synchroscope

Surges

When a synchronous machine is connected to a live line it must be in synchronism, otherwise corrective currents will be established. The first current impulse will carry the machine beyond synchronism, then it will fall below, and so on, gradually approaching synchronism in an oscillatory manner. These oscillations about synchronism are of course accompanied by corresponding current surges, which in large systems may produce very annoying disturbances and even interrupt the service by tripping circuit breakers. In very large machines these current surges may easily reach such values as to exert enormous forces on the end connections, and in certain cases may displace a conductor and thus wreck a machine.

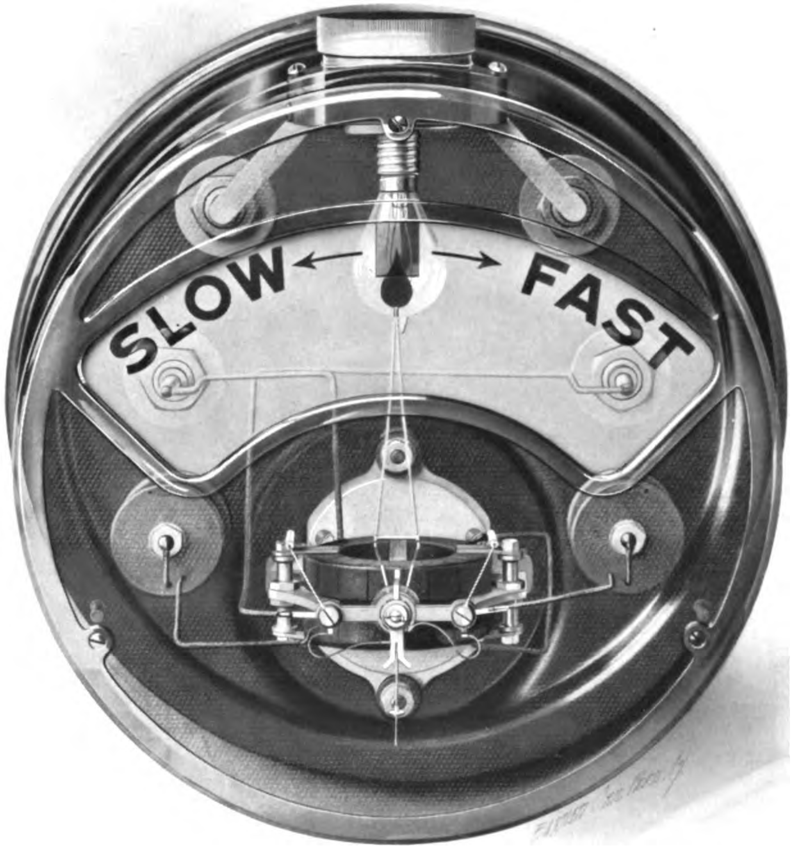

Fig. 33. Phantom View showing Lamp inside of Synchroscope

Synchronizing Lamps

In the days of small and medium size machines the condition of synchronism was determined by connecting incandescent lamps across the terminals of the two machines to be synchronized. As the machines approached synchronism the lamps would alternately become dark and light, and according to the method of connection, full synchronism was indicated either by the lamp glowing continuously at full brilliancy or remaining continuously dark.

Synchronizing dark is not to be recommended, as an inopportune failure of the lamp might easily deceive the operator and cause a serious disaster. Synchronizing light is fairly safe, but consumes much time and is not sufficiently sensitive. With

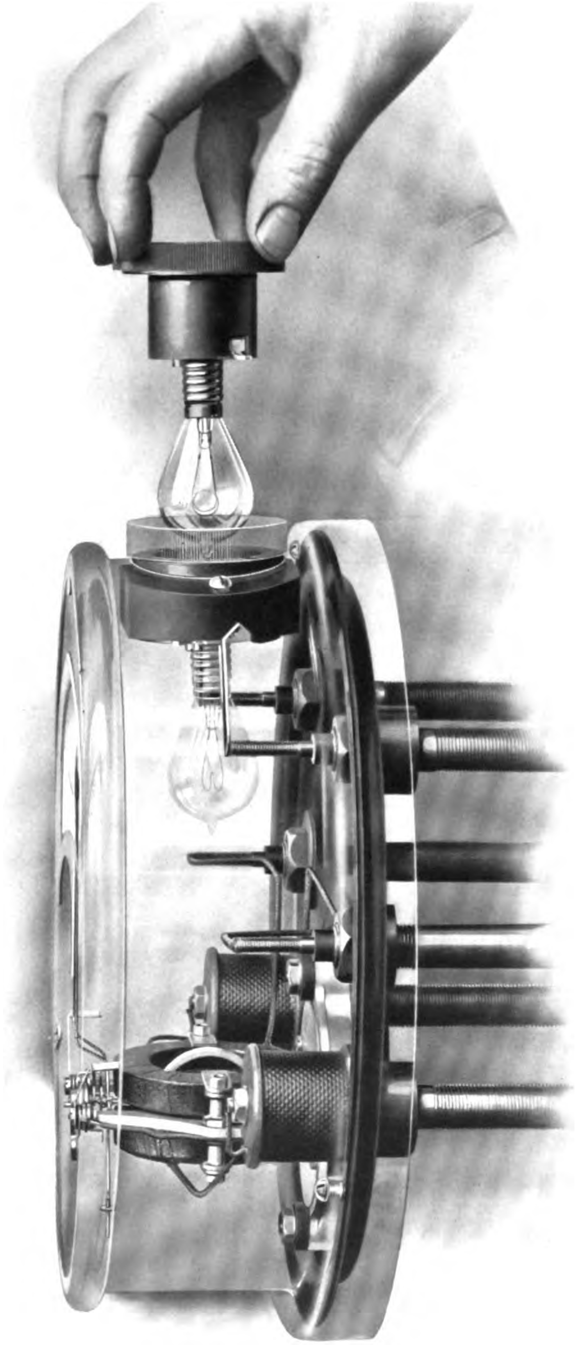

Fig. 34. Phantom View showing Relative Position of Lamp, Pointer and Scale

lamps there is no way of telling whether the incoming machine is fast or slow, and thus much time may be wasted in wrong manipulation of the speed. Furthermore, when the machines are running at the same frequency the lamp gives only the roughest notion of the phase displacement, which must be judged from the degree of brilliancy when synchronizing light, and cannot be judged at all when synchronizing dark.

The synchroscope is an instrument designed to indicate the condition of synchronism and to show in what respect the incoming machine differs therefrom. Most synchroscopes are of the rotating type and consist of a miniature induction motor, the rotor of which carries a pointer. The revolving field that drives the rotor is produced by the phase displacement between the e. m. fs. of the two machines to be synchronized. The direction of rotation indicates whether the incoming machine is fast or slow, and the position of the pointer indicates the phase displacement between the e. m. fs. when the frequency is right. Most of these instruments are equipped with friction brakes, and due to fluctuation of the coefficient of friction, the motion of the pointer is jerky and uncertain. In all of them the friction is very large, due to the excessive weight of the moving system, sliding contacts, brakes, etc., so that the rotating synchroscope is far from being a reliable device.

Rotating Synchroscopes

The Weston synchroscope has none of the disadvantages of the rotating type. It consists of a new model Weston switchboard electrodynamometer movement, mounted with the pointer behind a translucent glass scale and illuminated by a synchronizing lamp connected to synchronize light. The fixed coil is connected across the line through a resistor, and the movable coil, which is mounted on a staff supported in sapphire jewel bearings, is connected through a condenser across the incoming machine. The pointer stands normally in the middle of the scale. The mechanical construction of this instrument is similar to that of the Weston single-phase wattmeter, except that both the fixed and movable coils are wound with fine wire. The construction and design are described in Section 2 of this catalog.

Weston Synchroscope

Since the movable coil circuit contains a condenser, and the fixed coil circuit contains a resistor, having a slight inductance, the constants of these two circuits can be adjusted so that the currents in the two will be in exact time-quadrature when the e. m. fs. are either in phase or in phase opposition; therefore, under these conditions no torque will be exerted and the pointer will stand behind the black rectangle in the middle of the scale. Since the lamp is dark when the e. m. fs. are in phase opposition, and light when they are in phase coincidence and have the same frequency, the pointer will be seen at rest in the middle of the scale when perfect synchronism is attained.

When the e. m. fs. are not exactly in phase or in phase opposition, there will be torque tending to turn the movable coil; the value of the torque increasing with the phase displacement. The direction of the torque depends upon the relative directions of the currents in the coils; that is, the direction of deflection indicates whether one lags or leads with respect to the other.

If the two machines are not running at the same frequency, the phase displacement will continuously shift from phase coincidence through complete cycles of 360 time-degrees, and with it the torque will vary continuously from zero to plus maximum, back through zero to minus maximum, etc., thus causing the pointer to swing back and forth over the scale. Each swing denotes a shift in phase angle from quadrature plus or minus to quadrature minus or plus, and therefore it will coincide with a period of light or darkness, and the pointer will be seen only during every other swing; that is, it will appear to rotate in one direction. The direction of apparent rotation indicates whether the incoming machine is fast or slow and the speed of rotation is a measure of the amount by which the frequencies differ.

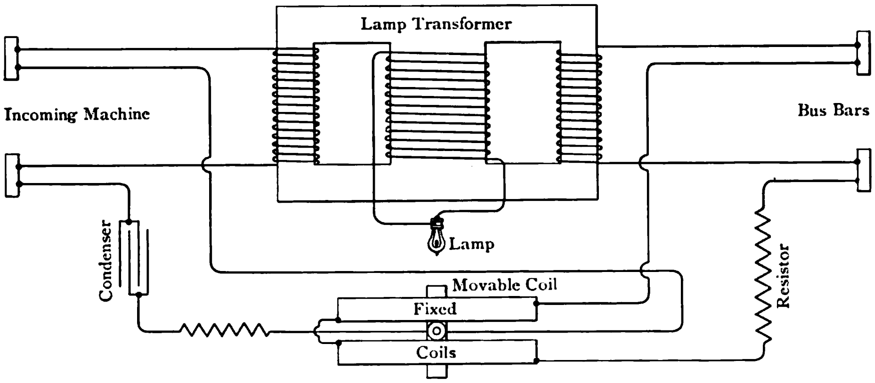

Fig. 35. Schematic Diagram of the Synchroscope Connections

If the machines have the same frequency but are not in phase coincidence, the pointer will come to rest at some point at one side or the other of the middle of the scale. The position of the pointer corresponds to the value of the electromagnetic torque, which, as was described in the foregoing paragraph, is a function of the phase displacement between the currents in the coils. The displacement per unit phase angle is large and fairly uniform, except around synchronism, where it is very large, a phase displacement of 5 deg. from synchronism producing a deflection of the pointer equal to ½ in.

The connections of the various operating parts of the synchroscope are shown schematically in Fig. 35, and the relations between currents, torque, phase displacement and speed are shown in the diagram in Fig. 36. The theory of operation of this extremely ingenious device may be clearly seen from the diagram in Fig. 36. At the top are shown two waves of different frequency, and the resultant of these two, which is active in the lamp, is drawn in

Theory of Operation

dotted lines. The shaded band represents the limits inside of which the current is not sufficient to light the lamp, and therefore, as long as the resultant maximum remains inside of this band no light will be seen. In the middle of the diagram the same

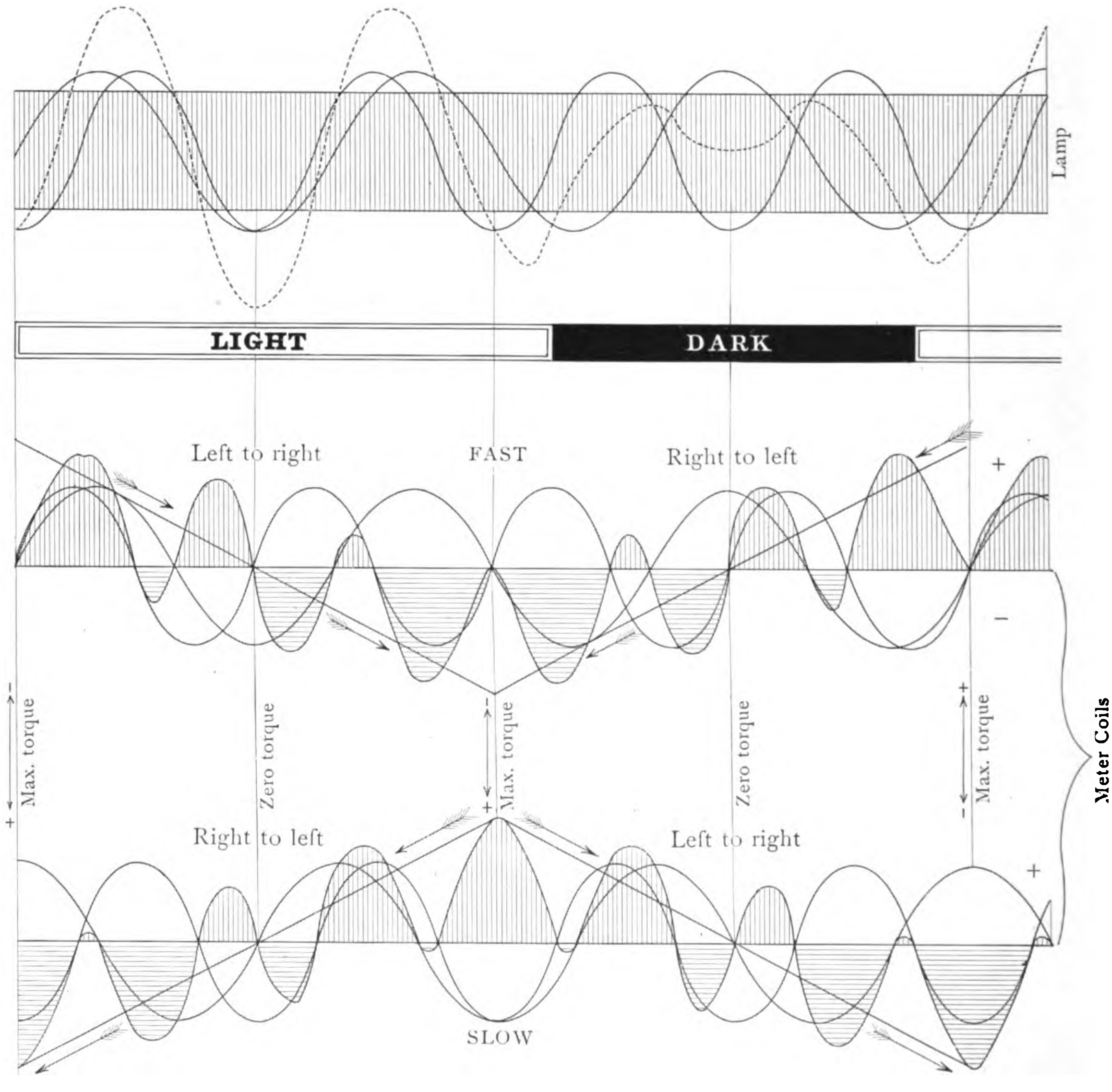

Fig. 36. Relations between Current, Torque and Phase Displacement in Synchroscope Circuits

waves are drawn, the faster one being assumed as belonging to the incoming machine; that is, connected to the movable coil through a condenser, which shifts it 90 time-degrees or a quarter period ahead. Therefore these curves represent the currents in the coils of the instrument. The instantaneous product of these two waves is a measure of the torque acting on the movable coil, and this is shown by the curve bounding the shaded areas. Vertical shading represents positive torque, while horizontal shading represents negative torque; positive indicating force directed toward the left, and negative indicating force toward the right. With maximum positive torque the pointer stands at the extreme left; as the torque decreases it swings toward the middle at zero torque, and then, as the torque reverses, it swings on to the extreme right, when the torque is a negative maximum. It is the average or resultant torque which determines the effective pull on the springs, the reversals being too rapid to impose fluctuations of such high frequency on the system.

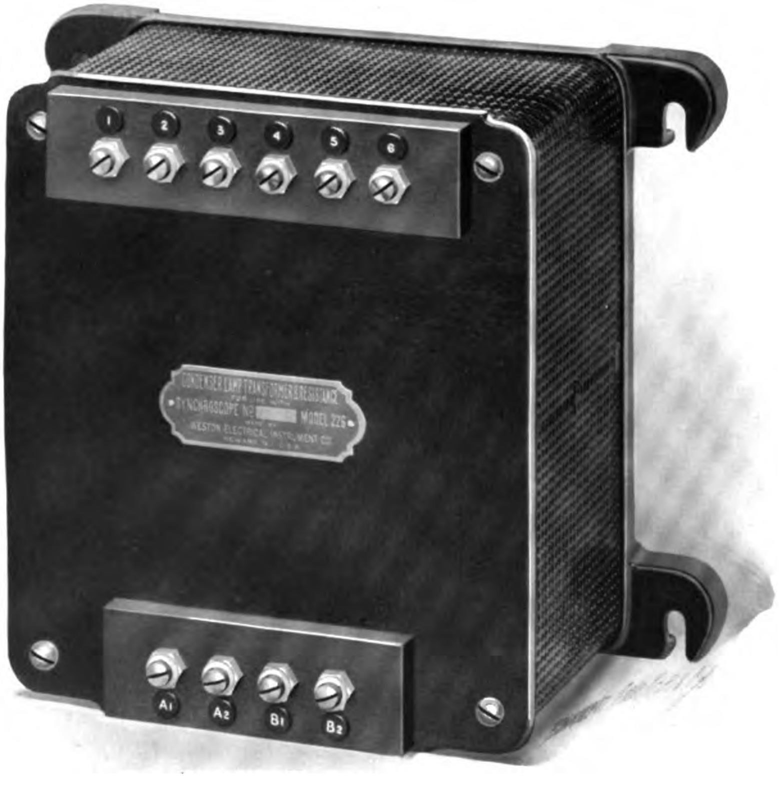

Fig. 37. Auxiliary Box for Synchroscope

The lowest set of curves is constructed in the same way as the middle set, except that the slow wave is considered as belonging to the incoming machine, and is therefore shifted a quarter period ahead.

From the diagram it is seen that when the incoming machine is fast the pointer moves from left to right while the dial is illuminated, and vice versa when the machine is slow. Of course, this is an exaggerated case chosen simply to demonstrate the principle. In practice such a large difference in frequency would cause a rapidly flickering light, and the pointer would flutter near the middle of the scale, being unable to follow such rapid changes. However, should we try to show waves of such small difference in frequency as is obtained in the practical operation of the synchroscope, it would take immense folding plates to get in enough waves to show a complete period of light and darkness.

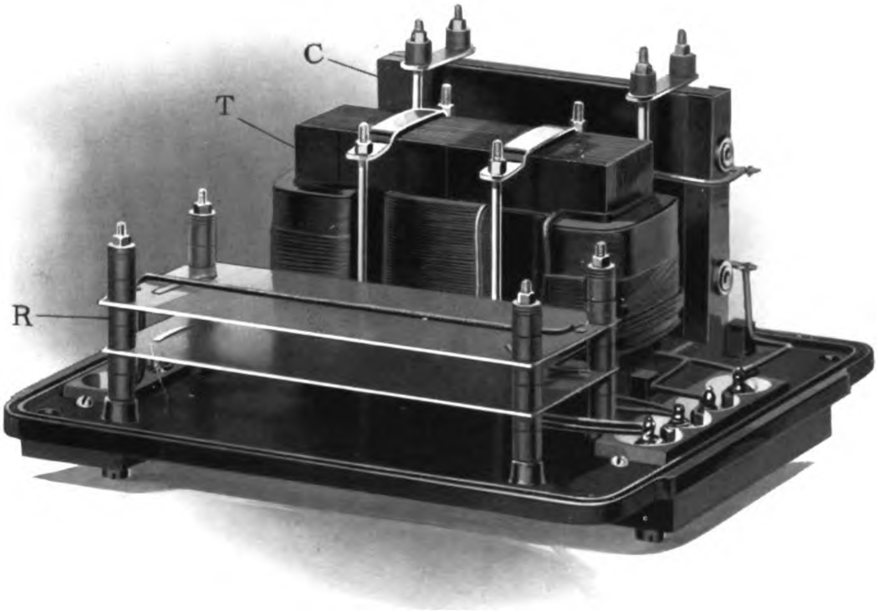

Fig. 38. Interior of Auxiliary Box, showing Condenser (C), Transformer (T) and Resistor (R)

Dial Lamp and Transformer

The synchronizing lamp is operated at low voltage, so as to increase the life of the lamp to a period of several years of normal service. However, to guard against shut-down in case of an accident to the lamp, several extra lamps are supplied with each instrument. The lamp is connected to the secondary of a special three-legged transformer having two primaries, one across each machine. The windings are arranged to give a secondary current, which is the resultant of the two primary currents, times the ratio of transformation. The transformer, the condenser and the resistor are mounted in one box to be attached to the back of the board. Fig. 37 shows an external view of the box and Fig. 38 shows the apparatus mounted on the back of the cover of the box with the sides and base removed; C is the condenser, T the transformer, and R the resistor. Every detail of these auxiliary devices has been given the same careful thought and attention as is usual with all Weston products.

Caution

If the cover of the instrument is ever removed from the case, care must be taken to remove the lamp from its socket before the cover is detached and not to replace it until the cover is again fastened in place. If this caution is not observed the lamp will bend the pointer and may damage the whole movable system. Figs. 33 and 34, which are phantom views of the synchroscope, show clearly the relative position of the lamp and pointer and need no further explanation to show the effect of removing or replacing the cover while the lamp is in position.

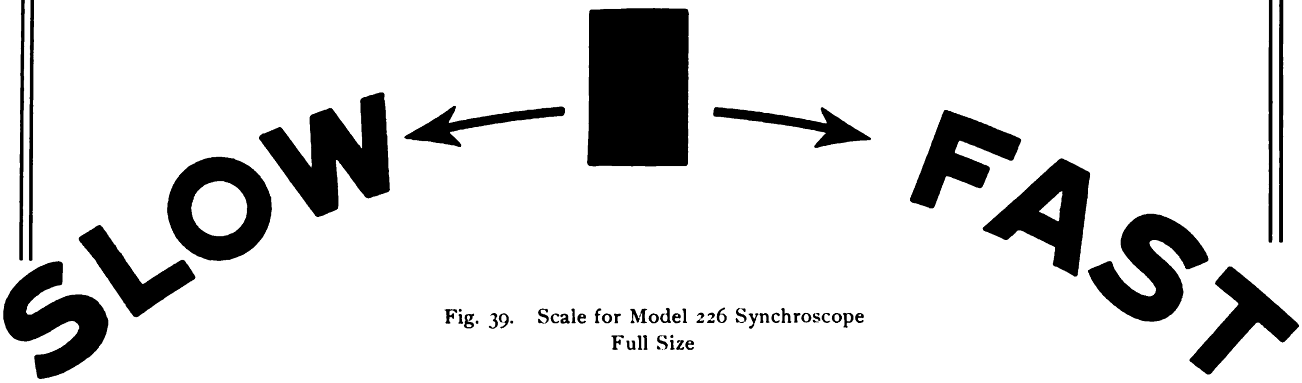

Fig. 39. Scale for Model 226 Synchroscope
Full Size

Condenser

The condenser is unique in that its capacity will remain practically constant independent of temperature changes throughout the usual range. The development of this condenser so that it could be manufactured on a commercial basis and in accordance with the usual precision methods of the Weston works, was an exceedingly troublesome problem, and was solved only after long and painstaking research and investigation.

Grounding

It will be noted that there is no direct electrical connection between the machines, either in the instrument or in the lamp transformer. Therefore, the secondaries of all instrument transformers (when used) can be grounded.

Voltage Frequency and Power Consumption

The synchroscope is regularly built for 110 volts, but it will operate satisfactorily at from 95 to 130 volts. For higher voltages potential transformers must be used. On account of the condenser the synchroscope is adjusted to the normal frequency of the circuit on which it is to be used. However, this adjustment is not so necessary as might at first appear; for instance, a 60-cycle 110-volt Weston synchroscope under test showed that variations of frequency between 40 and 80 cycles and of e. m. f. between 100 and 130 volts affected but slightly the accuracy of the instrument. The results are tabulated on following page.

Notwithstanding the wide range of frequency and voltage variations which may be tolerated without appreciable sacrifice of accuracy, it is always advisable to state the exact voltage and frequency of the circuit when ordering, so that the condenser may be adjusted to give the best possible results.

Effect of Variation in Frequency at 110 Volts

Frequency, cycles per sec.	40	50	60	70	80
Phase displacement for ½ in. movement of pointer, deg.	10	8	6.66	5.7	5

Effect of Variation in Voltage at 60 Cycles

E. m. f., volts	100	110	120	130
Phase displacement for ½ in. movement of pointer, deg.	8.07	6.66	5.6	4.77

As will be seen from the results of the tests shown in the above tables the accuracy of the synchroscope is scarcely affected by changes in voltage or frequency. Nevertheless it is not advisable to subject a 60-cycle synchroscope to working frequencies below 50 nor above 70 cycles per second, on account of the heating, and in order to get the very best results it is advisable always to state the normal frequency and voltage of the system.

The power consumption is extremely small; the entire device, including the lamp, requires only 0.15 amp. from each machine at 110 volts.

Signal Advantages

The Weston synchroscope has so many advantages over all other instruments intended for the same purpose that it may be well briefly to summarize its signal advantages and contrast them with the signal disadvantages of certain other types.

1. *The indications are infallible.* The rotating type has been known to indicate fast when the machine was slow, and vice versa; in fact, by skillful manipulation the pointer of some rotating synchroscopes can be reversed at will, irrespective of whether the machine is fast or slow.

2. *There is only one object to observe.* In order to render other types of synchroscope reliable, synchronizing lamps must be used, and therefore the attendant's attention is divided between the lamps and the instrument.

3. *The movement of the pointer is smooth and certain; it inspires confidence.* The rotating type with a friction brake rotates fast when the difference in frequency is considerable, and as synchronism is approached it tends to stick, and its motion is jerky and uncertain. In one well-known make of rotating synchroscope a pointer is painted in the position indicating perfect synchronism. When the frequency difference is large, the real pointer rotates so fast that it becomes invisible and it is extremely easy to mistake the painted pointer for the real one and thus cause a serious disaster by throwing in the switch too soon.

4. *Long useful life and permanent accuracy throughout its life.* This characteristic is due to superior construction, the extremely light weight of the movable system, the efficiency of the damping system and the absence of sliding contacts.

5. *It indicates exact synchronism* within 1 deg. of true phase coincidence over a wide range of frequency and voltage.

6. It constitutes a very simple and absolutely *perfect solution* of all problems involved in coupling alternating-current machines in parallel without danger or sensible disturbance of circuit conditions, and we venture to predict that this synchroscope will eventually supplant every other type now known.

Price List of Model 226 Synchroscopes

Volts	Cycles	Code Word	List Price	Volts	Cycles	Code Word	List Price
100 to 125	25	Syncro	$62.50	100 to 125	50	Syncue	$62.50
	40	Syncyt	62.50		60	Syncone	62.50

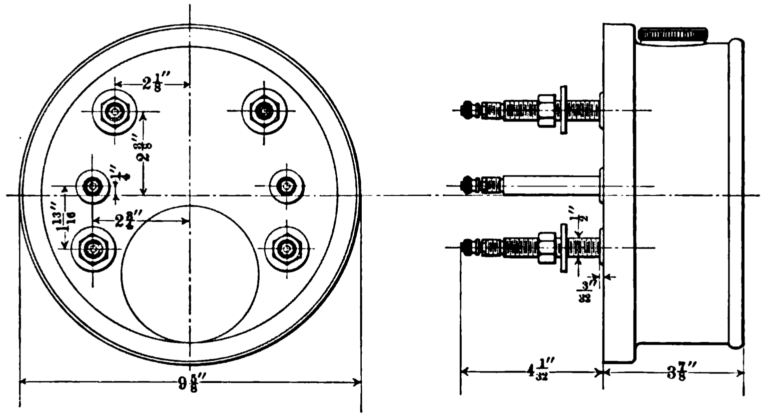

Fig. 40. Dimensions of Model 226 Synchroscope

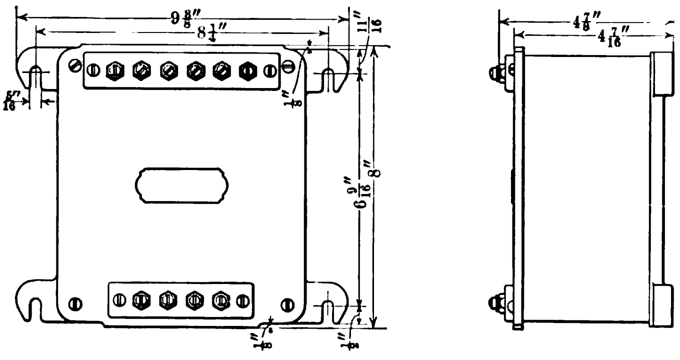

Fig. 41. Dimensions of Auxiliary Box for Model 226 Synchroscope

SECTION 5

Weston Power-factor Meter

THE power, in watts, transformed in a circuit is numerically equal to volts × amperes × power-factor; therefore, since the conductor material in a circuit must be proportioned to carry the current irrespective of the actual power, a low power-factor load requires larger generators, transformers, line conductors, etc., than does a unity power-factor load.

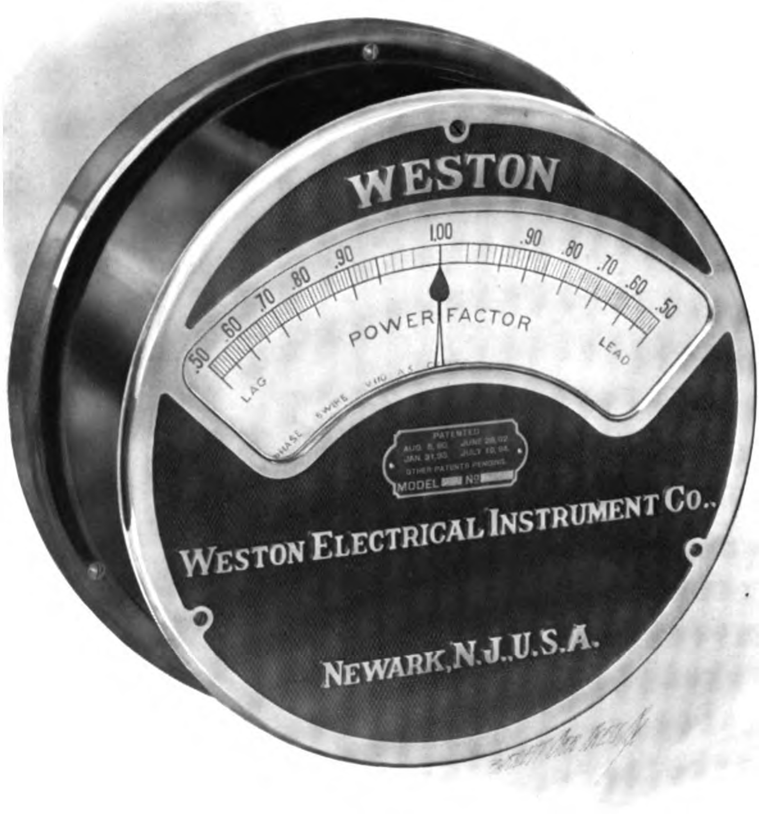

Fig. 42. Model 215 Power-factor Meter

Assuming sine wave quantities, the power-factor of a load is a function of the time-phase angle between the e. m. f. and the current. The power-factor for a given phase displacement is the same whether the current lags behind or leads the line e. m. f.; however, lagging current has a much worse effect on line regulation than has leading current. On commercial circuits, the load current usually lags behind the line e. m. f., therefore, in the operation of long lines and large distribution systems, the value of power-factor becomes of great economic importance.

Power-factor Regulation

Synchronous machines, such as synchronous motors and synchronous converters, may be made to take any desired amount of leading or lagging current within the limits of their current-carrying capacity, by varying the value of their exciting current; therefore, such machines may be used to compensate the useless current in the line and thus adjust the power-factor to any desired value.

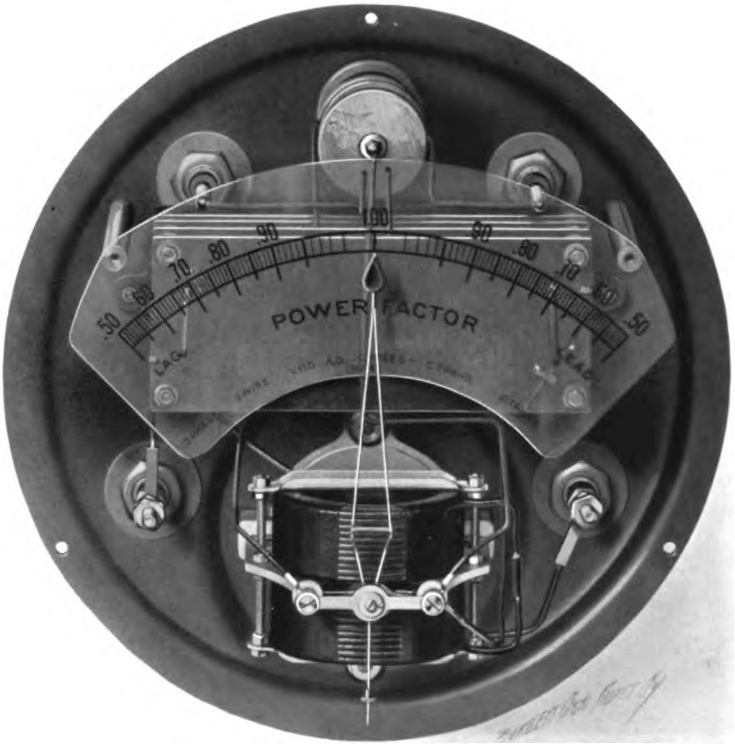

Fig. 43. Phantom View of Interior of Model 215 Power-factor Meter

Wherever power-factor adjustment is attempted a power-factor meter is necessary, as it is out of the question to calculate the power-factor from the readings of wattmeters, voltmeters and ammeters. Since power-factor adjustment is made solely to save money and to produce good regulation, it is of great importance to have a meter which gives accurate and reliable indications under all possible service conditions.

Construction

The Weston power-factor meter is a special form of Weston electrodynamometer. Its movable system consists of two circular coils arranged on the same staff and in planes at right angles to each other. If a power-factor meter is to perform properly its functions, the magnetic strength of these coils must be equal, and they must be exactly located in perpendicular planes; that is, they must be identical in construction and be accurately and permanently located with reference to each other.

The common way of making the movable coils of a power-factor meter is to wind two separate coils and then slip one inside the other, as shown in Fig. 44. Such a construction is inherently wrong; it is impossible to get even approximate magnetic equality with two such coils, and, furthermore, this type of construction is unnecessarily heavy and makes no provision for the establishment or maintenance of a definite relative position of the coils.

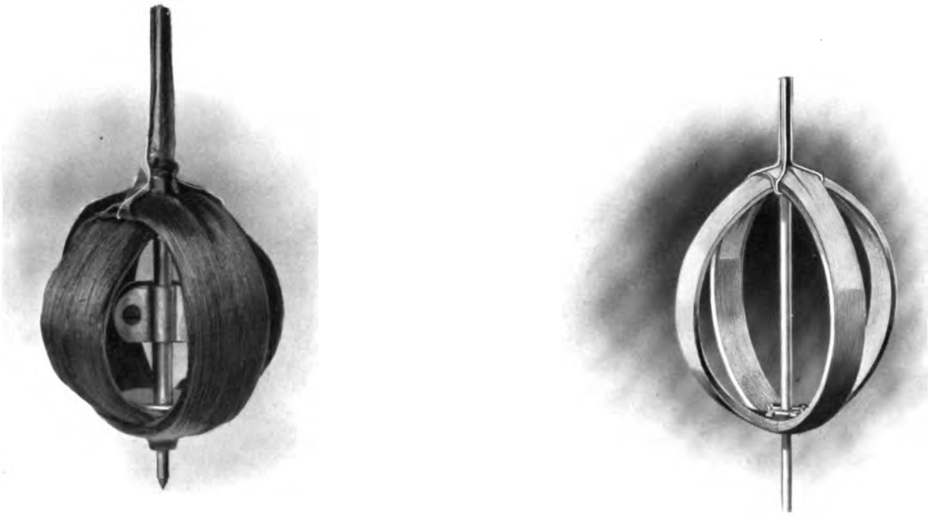

Fig. 44. Comparison between Ordinary and the Weston Construction of the Movable Coils

The movable coils of the Weston power-factor meter are practically identical in magnetic strength when traversed by the same current, and are accurately and permanently located in planes at right angles to each other. In these respects the Weston power-factor meter is both novel and unique. The coils are wound by machine and interlaced layer for layer at diametral crossing points. The completed coil is then treated with a special cement which gives it exceedingly great rigidity, and thus assures a permanent relative location of the coils.

The general construction is quite similar to that of the Weston single-phase wattmeter and is described in detail in Section 2.

Theory of Operation

On polyphase systems, the movable coils are connected across leads in which the e. m. f. differs in time-phase, while on single-phase circuits a phase-splitting device is used. When the current in one of the movable coils is in time-phase with that in the fixed coil it will place itself parallel with the fixed coil. If the current in the fixed coil reaches its maximum at some time intermediate between the time of maximum current in either of the other coils, the movable coils will take a position such that the resultant maximum field, which is in time-phase with the fixed field, due to the fixed coil, will coincide with the fixed field.

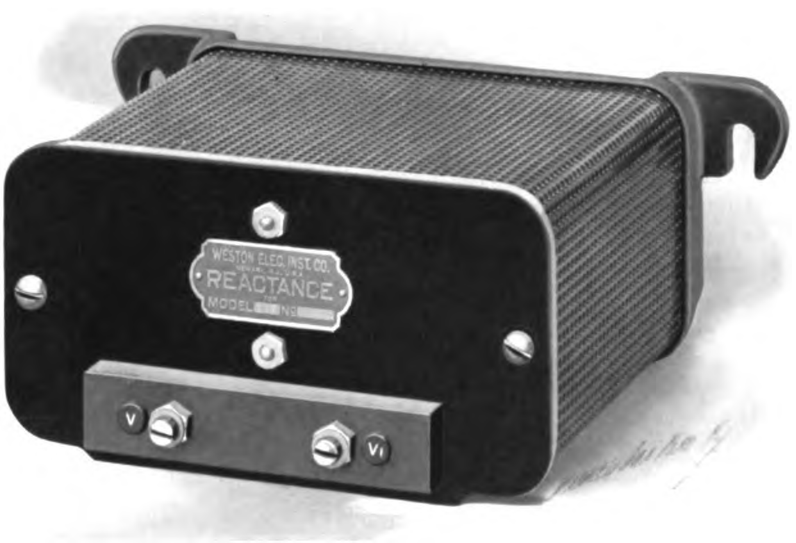

Fig. 45. Auxiliary Box for Use with Model 215 Power-factor Meter

Since the fixed field is in time-phase with the load current, and the field of one of the movable coils is in time-phase with the e. m. f. between leads, the space position of the resultant field of the movable coils, which is in phase with the fixed field, will vary with the phase angle between e. m. f. and current; that is, the deflection of the movable system is a measure of phase-angle or power-factor.

Accuracy

The indications of the instrument are practically free from errors, the greatest error between $\frac{1}{5}$ load and full load being less than 1 per cent. Eddy currents, inductance, temperature errors, etc., have been practically eliminated, so that a given instrument will retain its accuracy independent of frequency, of wave form as usually found in good commercial practice, of load and of room temperature. The power consumption is extremely low, the current being only 0.050 amp. at full load.

Scale All Weston power-factor meters have the same scale, reading from 0.50 lagging to 0.50 leading. The scale divisions are very open and quite uniform, except near power-factor 1.00, where the instrument is extremely sensitive. A change in time-phase angle of 5 deg. at unity power-factor will produce a deflection of the pointer of 0.35 in. Special scales down as low as power-factor 0.30 may be had upon request and without extra cost.

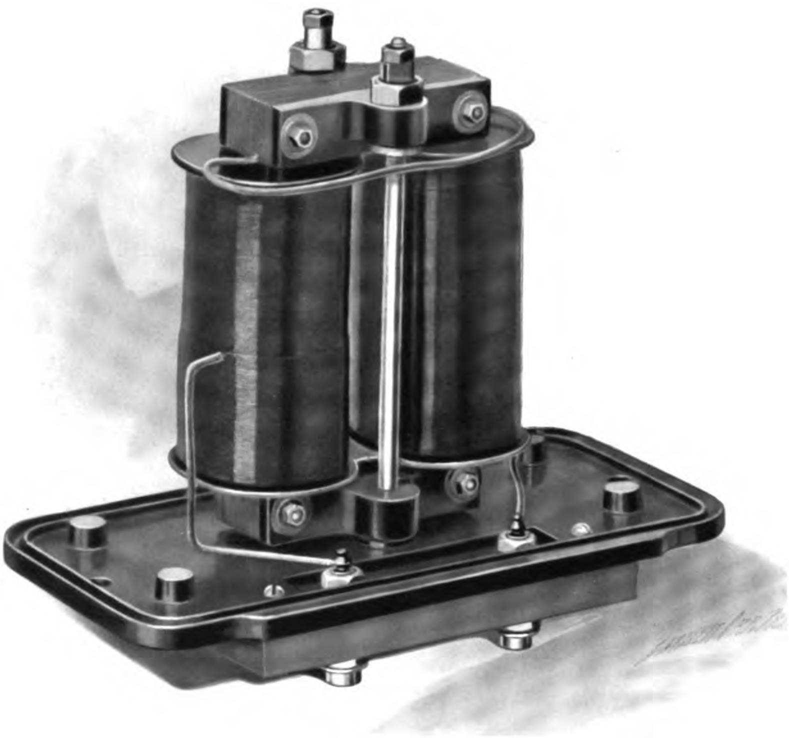

Fig. 46. Reactor for Use with Model 215 Power-factor Meter

Ranges Single-phase meters use a reactor and resistor to produce phase displacement between the currents in the movable coils; therefore single-phase meters must be used at the frequency for which they were calibrated. Single-phase power-factor meters are designed for all standard frequencies: 15, 25, 40, 50, 60, 125 and 133 cycles per second.

Single-phase and two-phase three-wire meters may be had in ranges for direct connection to circuits up to 300 volts and 100 amp. Three-phase meters have the same current limit, but may be had for direct connection to circuits up to 750 volts. All power-factor meters on circuits above 750 volts must be used with both current and

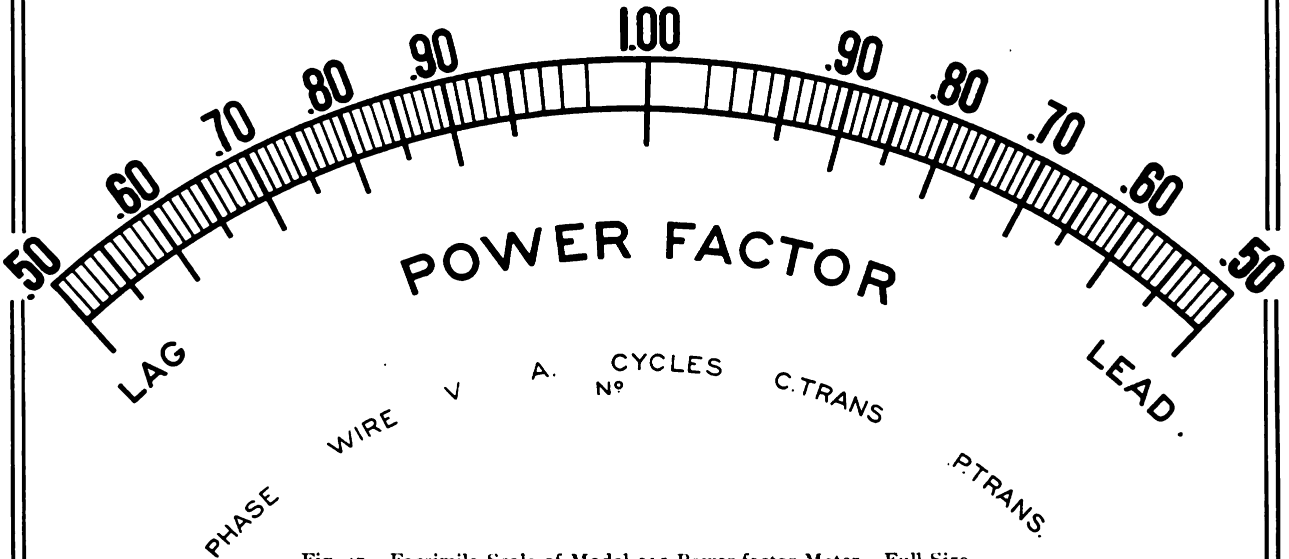

Fig. 47. Facsimile Scale of Model 215 Power-factor Meter. Full Size

potential transformers, the secondary current and e. m. f. being respectively 5 amp. and 110 volts. All two-phase four-wire power-factor meters are used with two potential transformers, but are built with series coils in sizes up to 100 amp. current-carrying capacity. For larger currents, or for e. m. fs. over 750 volts, current transformers as well as potential transformers are necessary.

All two-phase meters are self-contained; that is, the resistors in series with the shunt coils are mounted in the case. Three-phase meters are self-contained for e. m. fs. up to 300 volts; from 300 to 750 volts the resistors are mounted in a separate box placed on the back of the switchboard. Single-phase instruments are all supplied with an external box, which contains the reactor used to produce the phase displacement in the shunt circuits.

Reactor

The reactor is especially designed for use with Weston instruments, and its every detail has been developed with the thoroughness which is characteristic of all Weston products. The neatness of the design and the high class of the workmanship are immediately apparent from inspection of Fig. 46, which shows the auxiliary reactor mounted on the back of the cover to the auxiliary box.

The reactor core is made up of very thin laminations of special alloy steel having low hysteretic constant and high permeability. All core material is submitted to a special treatment that fixes its properties and renders it non-aging. The laminations are securely fastened together so as to prevent vibration and relative motion between them, which would cause a change in the value of the reactance. The reactance is adjusted to its correct value by varying the air gap in the magnetic circuit, special provisions having been made to facilitate a fine adjustment.

In reactors of this kind it is usual to put the air gap outside where it can be seen, and when built in this way, stray or leakage fields of considerable magnitude are set up about the gap, which will seriously impair the accuracy of the indications of the power-factor meter, and also interfere with electrical instruments in the neighborhood. In the Weston reactor there are two air gaps, one inside of each coil. By thus placing the gaps, the turns on the coil act to suppress all tendency to form a stray field about the gaps and thus the reactance remains constant with varying load and no external magnetic disturbances are produced. By using high-grade materials especially adapted to the purpose and extreme care in design and construction, the losses have been reduced to a negligible quantity and the temperature errors have been practically eliminated, thus rendering the device accurate and reliable in operation.

Advantages The chief advantages of the Weston power-factor meter over all others are due to its novel features, superior design and construction:

1. *It is extremely accurate*, being guaranteed to indicate the true phase angle to within 1 per cent under all conditions of ordinary service from $\frac{1}{5}$ load to full load.

2. It is the only electrodynamometer power-factor meter that *can be used on single-phase circuits* without sacrifice of accuracy. Indeed, no other American maker cares to recommend this type of power-factor meter for use on single-phase circuits. The Weston power-factor meter will give equally good results on single-phase and polyphase circuits, except that the single-phase meter is not quite so free from errors due to bad wave distortion as is the Weston polyphase power-factor meter.

Price List of Model 215 Power-factor Meters

(Two-phase three-wire and four-wire, and three-phase three-wire)

Rating			Code Word	List Price	Rating			Code Word	List Price
Volts	Amperes	Scale			Volts	Amperes	Scale		
100 to 150 Self-contained	5	50–1–50	Powfair	$55.00	400 to 600 External Resistor	5	50–1–50	Powfine	$70.00
	10	50–1–50	Powface	55.00		10	50–1–50	Powfide	70.00
	20	50–1–50	Powfan	60.00		20	50–1–50	Powfod	75.00
	50	50–1–50	Powfep	60.00		50	50–1–50	Powfone	75.00
	100	50–1–50	Powfent	65.00		100	50–1–50	Powfat	80.00
200 to 300 Self-contained	5	50–1–50	Powfer	60.00	600 to 750 External Resistor	5	50–1–50	Powfoge	75.00
	10	50–1–50	Powfut	60.00		10	50–1–50	Powfots	75.00
	20	50–1–50	Powfuz	65.00		20	50–1–50	Powfyde	80.00
	50	50–1–50	Powfub	65.00		50	50–1–50	Powfynt	80.00
	100	50–1–50	Powfist	70.00		100	50–1–50	Powfyre	85.00

NOTE 1. Single-phase power-factor meters require an auxiliary device for splitting the phase, which is mounted in an external box. The price of single-phase power-factor meters including the auxiliary device is $10.00 more than the price of corresponding range polyphase meters as given in the above table.

NOTE 2. When ordering single-phase power-factor meters always specify the frequency.

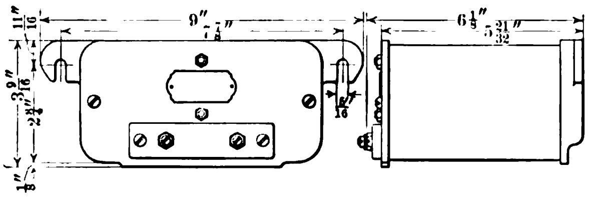

Fig. 50. Dimensions of Auxiliary Box for Use with Model 215 Power-factor Meter

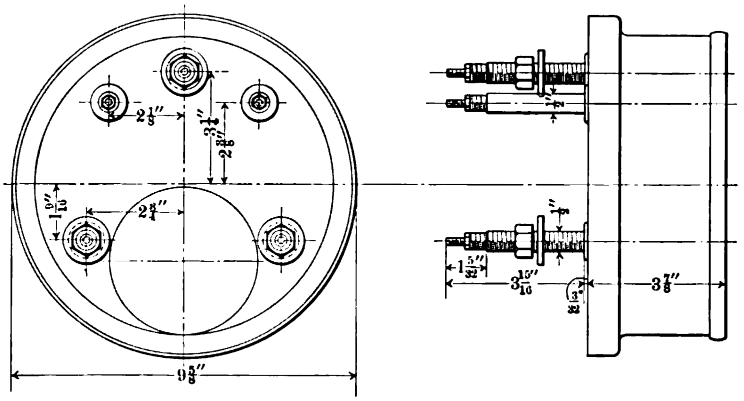

Fig. 48. Dimensions of Model 215 Power-factor Meter. Range, 5 to 20 Amp.

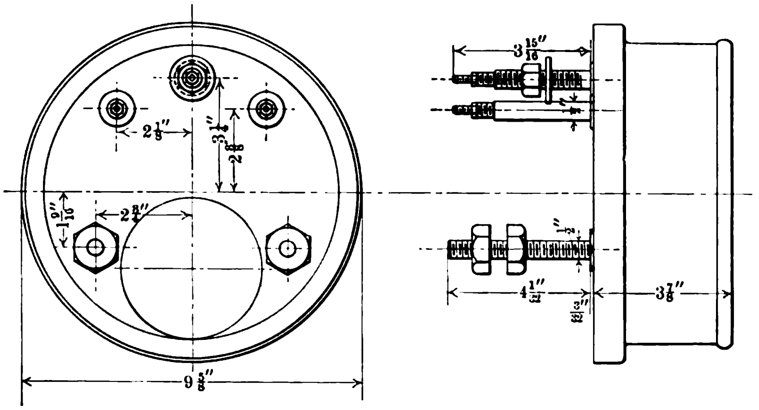

Fig. 49. Dimensions of Model 215 Power-factor Meter. Range, 50 to 100 Amp.

SECTION 6

○

Weston Frequency Meter

THE speed of synchronous and induction motors, synchronous converters, motor-generators, etc., is fixed by the frequency of the system, and any change in frequency will be accompanied by a corresponding change in speed. Changes in frequency also cause corresponding changes in reactance of the circuits, and in extensive systems such changes will result in appreciable variations in voltage with all the attendant disadvantages. Therefore not only is it important that the frequency be kept constant, but it should be kept at a definite and accurately determined value.

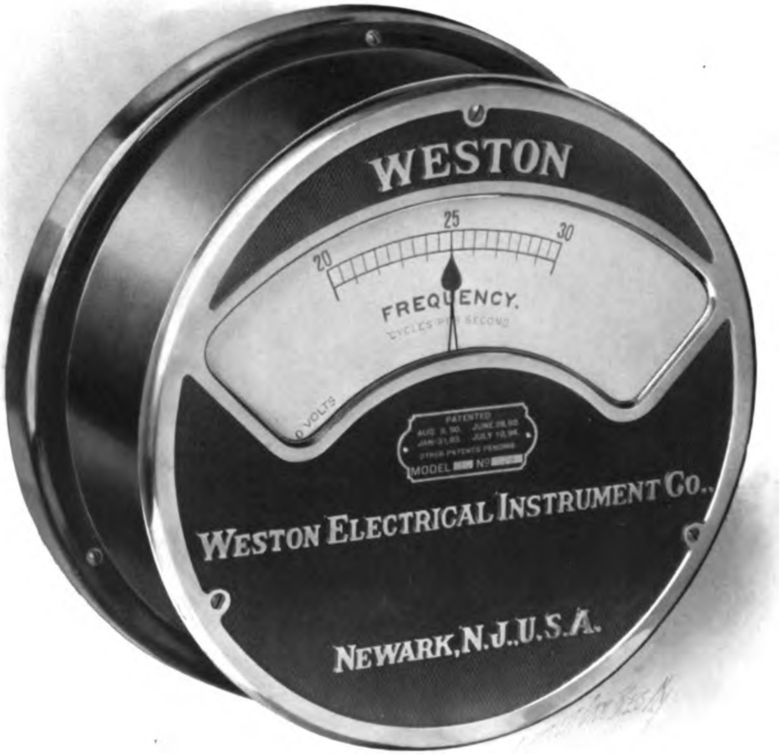

Fig. 51. Model 214 Frequency Meter

The Weston frequency meter indicates accurately the instantaneous value of the frequency of the system to which it is connected. Its movement is of the soft-iron type; however, it does not belong to the same class as the Weston soft-iron ammeters and voltmeters.

Construction

There are two fixed coils, each made up of two sections. They are wound flat and one is slipped inside the other and at right angles to it, as is clearly shown in Fig. 52. The movable system consists of a staff carrying a damper, an iron needle and a pointer; it is mounted in highly polished sapphire jewel bearings. There are no springs or other connections to the movable system, therefore, it is perfectly free to rotate. The movable system is so extremely light that the damper is reduced to one vane arranged to counterbalance the pointer. The essential features of this damper are the same as the balanced damper used on the

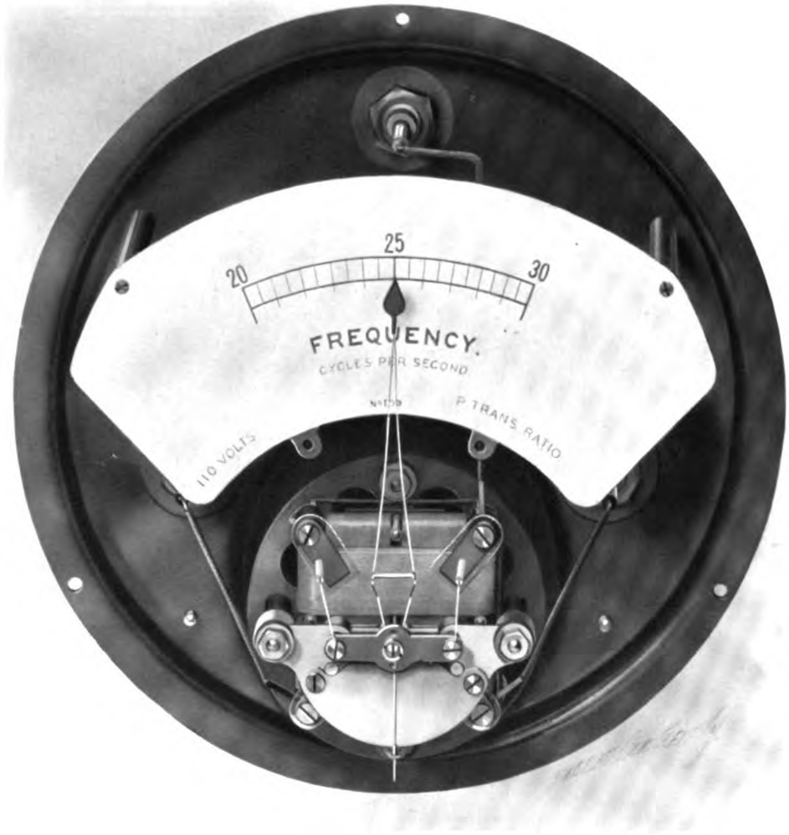

Fig. 52. Interior View of Model 214 Frequency Meter

other instruments, and described in Section 2 of this catalog. It is mounted on the staff above the fixed coils instead of below, as in the electrodynamometer instruments. This arrangement of the damper is similar to that used in the soft-iron voltmeters and ammeters.

The shape of the fixed coils is such as to establish with minimum material a strong field of uniform density, such as is necessary to the production of uniform scale. The needle is extremely thin and is made of a special alloy having low hysteretic constant.

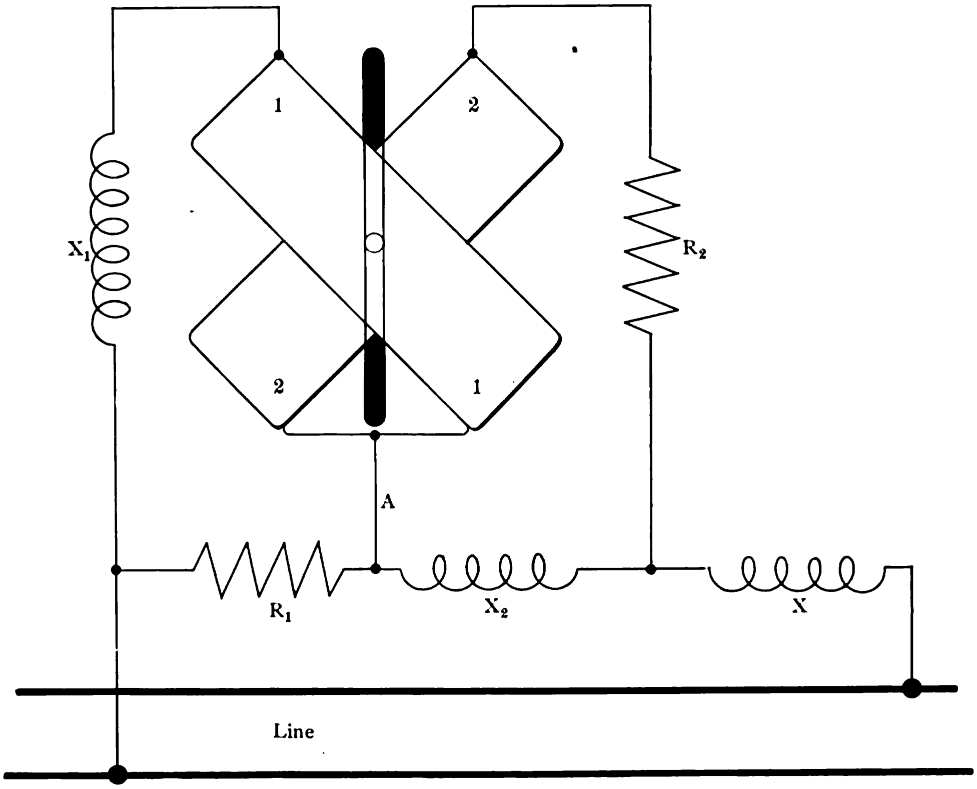

Fig. 53. Schematic Diagram of Connections of Model 214 Frequency Meter

Theory of Operation

The coils are connected in series across the line, with a reactor in series with one and a resistor in series with the other. A resistor is connected in parallel with one coil and the reactor, and a reactor is connected in parallel with the other coil and the resistor; then the whole combination is connected in series with a reactor, the purpose of which is to damp out the higher harmonics. The circuits, shown in Fig. 53, form a Wheatstone bridge, which is balanced at normal frequency. An increase in frequency will increase the reactance of the reactors and thus upset the balance of the bridge, allowing more current through one coil and less through the other.

Therefore every change in frequency is accompanied by a corresponding shifting of the space position of the resultant field, which is indicated by the pointer.

The arrangement of circuits here used produces a very open scale, which is one of the most striking features of this instrument. There are frequency meters now on the market which have a resistor in series with one coil and a reactor in series with the other; therefore, any change in frequency affects only one coil, while in the Weston frequency meter, every change in frequency affects both coils, decreasing the strength of one and increasing that of the other.

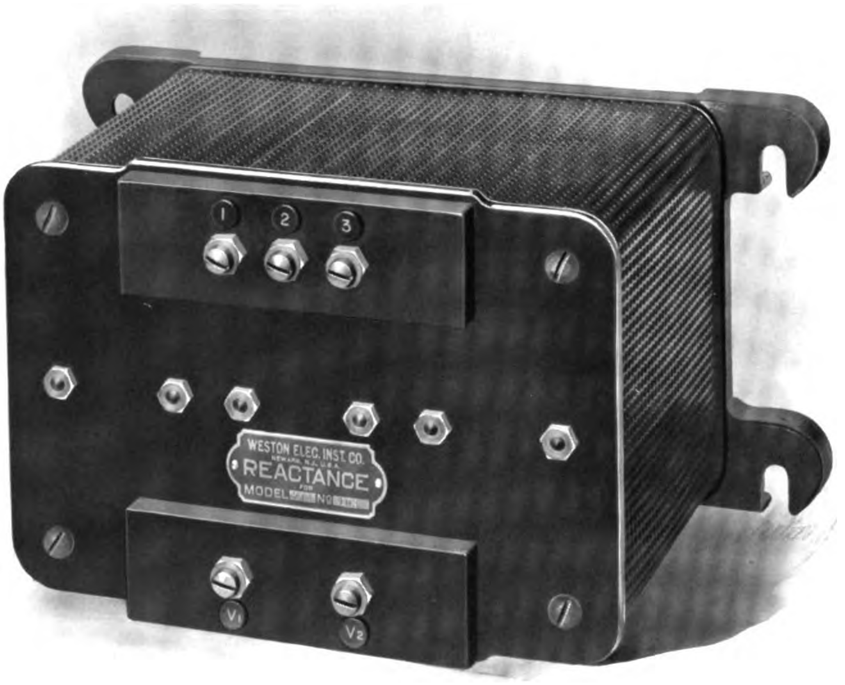

Fig. 54. Auxiliary Box for Use with Model 214 Frequency Meter

Accuracy

The indications of a given instrument are practically independent of variations of e. m. f.; a change in e. m. f. from 75 to 150 volts will produce an error of less than 1½ per cent. However, the normal e. m. f. should preferably be stated when ordering. Within the range of wave distortion found in commercial practice no appreciable error is caused thereby.

Ranges These instruments are built for direct connection to circuits up to 150 volts. Above this voltage, potential transformers with a secondary e. m. f. of 110 volts are used. Frequency meters are calibrated for all the standard frequencies: 20, 25, 40, 50, 60 and 125 cycles per second.

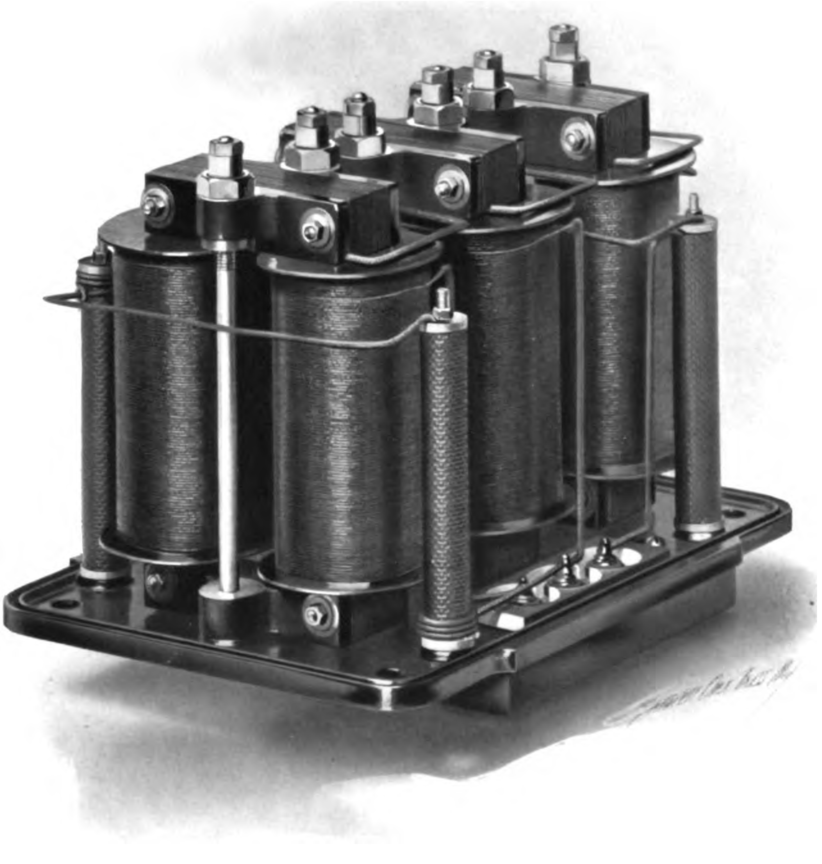

Fig. 55. Reactors and Resistors for Use with Model 214 Frequency Meter

Reactors The reactors and resistors are mounted in a separate box, which can be attached to the back of the switchboard. The reactors are of the same type of construction as that employed with the single-phase power-factor meter described in Section 5 of this catalog. They are built up like miniature core-type transformers with an air gap in each leg. The laminations are extremely thin and thoroughly insulated.

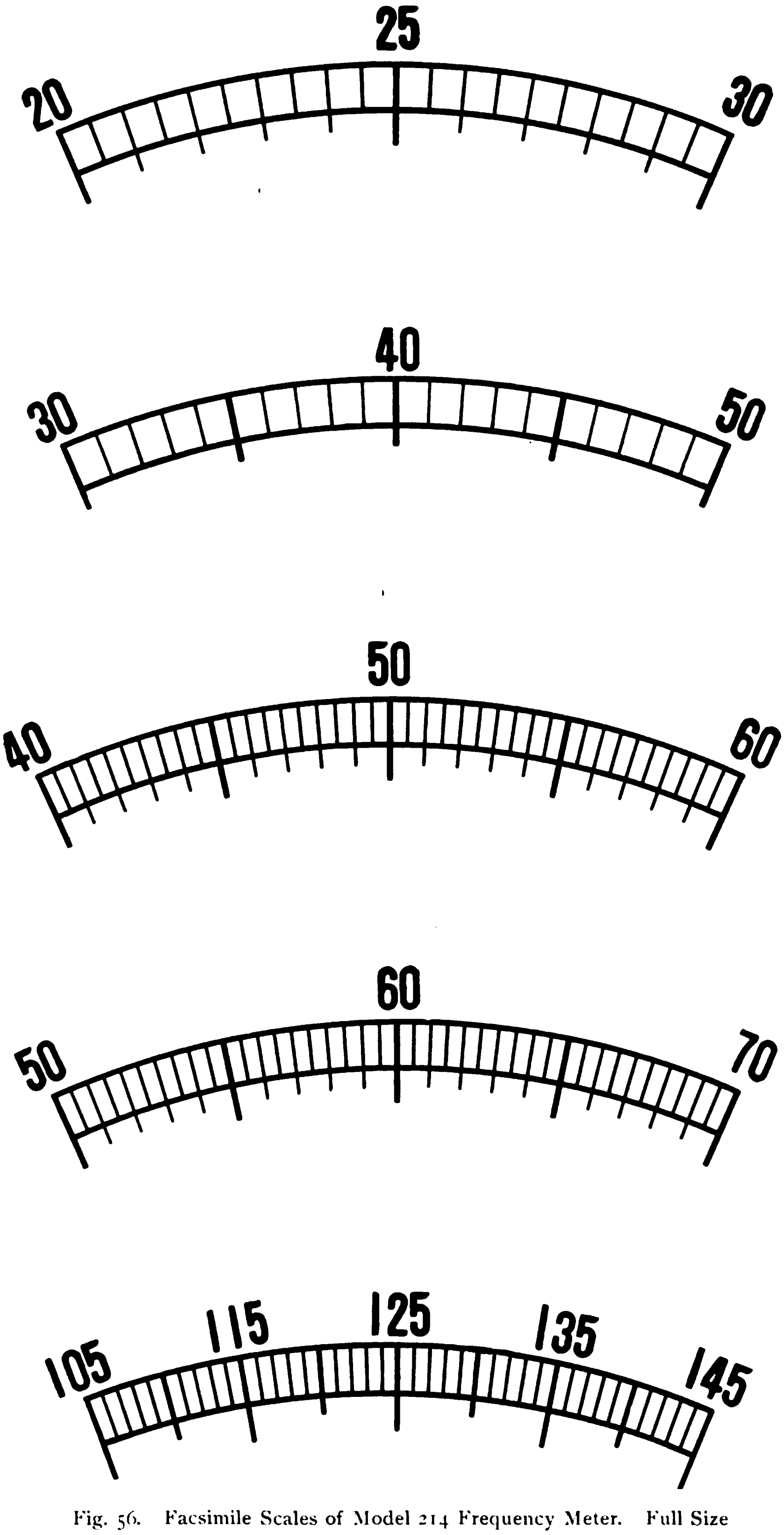

Fig. 56. Facsimile Scales of Model 214 Frequency Meter. Full Size

They consist of special steel chosen for its low hysteretic constant and high permeability. In order to prevent vibration and consequent disturbance of the reluctance of the circuit, the laminations are firmly bolted together, and the bolts carefully insulated to prevent eddy currents. The formation of stray or leakage fields about the air gap, which are so characteristic of the usual form of commercial reactors, is avoided by winding the coils over the gaps and thus shielding them by the conductor turns. By use of high quality core material, and exceeding care in construction, the core losses and leakage have been reduced to a negligible quantity, which is of great importance from the standpoint of accuracy. By this construction the temperature errors usually so large in devices of this kind have been practically eliminated.

Price List Model 214 Frequency Meters

Volts	Cycles	Code Word	List Price	Volts	Cycles	Code Word	List Price
100	20	Freind	$60.00	100	60	Fredint	$60.00
to	25	Freold	60.00	to	125	Frecy	60.00
125	40	Freoce	60.00	125	133	Frecam	60.00

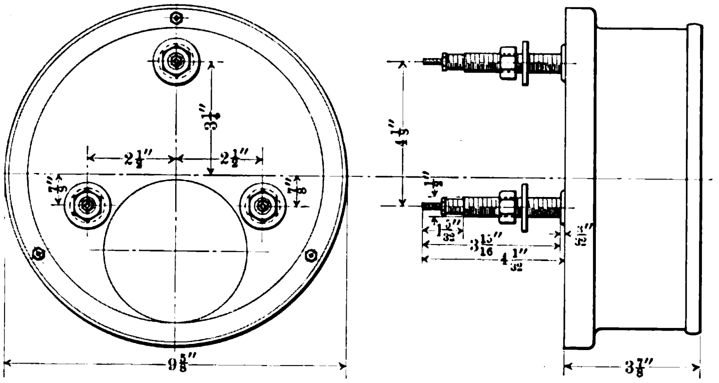

Fig. 57. Dimensions of Model 214 Frequency Meter

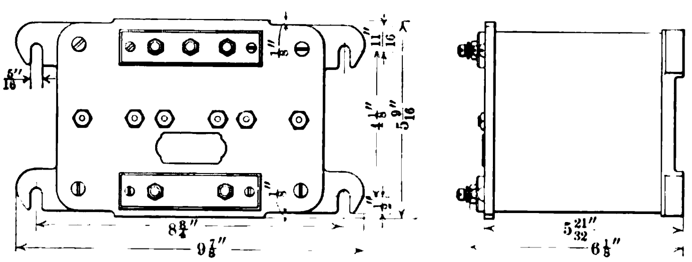

Fig. 58. Dimensions of Auxiliary Box for use with Model 214 Frequency Meter

SECTION 7

O

Weston Soft-Iron Switchboard Instruments

SOFT-IRON, or electromagnetic, instruments depend for their action upon the behavior of a piece of iron in a magnetic field, which varies with the quantity to be measured. This principle may be applied in an almost infinite number of ways, and, therefore, it is difficult to make any general statements regarding the characteristics of this class as a whole.

The earliest types of soft-iron instruments were monstrosities; the movable system often weighed from several ounces to several pounds. Needless to say such instruments, regardless of any other errors they might have, would be useless on fluctuating loads. Even now there are instruments of this type in which the movable system weighs ounces, and for the benefit of those who have no quantitative ideas on the subject, we may say that such instruments as these are seldom of any value, and especially is this true in making measurements on circuits carrying fluctuating loads; furthermore, such instruments have an extremely short useful life due to rapid wear at the pivots. In no Weston instrument of any type does the movable system weigh more than a few grains.

Development of Soft-Iron Instruments

When Dr. Weston first began his work of developing a reliable direct-current instrument, he studied among others the soft-iron or electromagnetic type, and constructed various forms of it; however, as is well known to-day, after thoroughly investigating every type of electrical instrument, he finally turned to the permanent magnet as the only proper solution. At that time it was generally believed that any instrument depending for its action upon a so-called "permanent magnet" could never be rendered reliable. It took years to convince the public of the absolute truth of all the claims made for the permanent magnet instrument at the time of its introduction. However, to-day it is universally recognized as the standard of excellence and reliability, which all other indicating instruments may approach but not surpass.

Although Dr. Weston discarded the soft-iron type in favor of the permanent magnet type, he recognized its many advantages as a switchboard meter, and later developed a line of direct-current soft-iron instruments, which he called "indicators," because of the approximate character of their readings. The most prominent characteristics of these instruments were simplicity, durability and cheapness. They were enthusiastically received, as there was a great demand for a cheap instrument; however, although these instruments were very much better than any soft-iron instrument that had previously been produced, they were so little representative of Weston quality that it was soon decided to withdraw them from the market and continue the investigations of the type.

After years of careful research, which involved the production of new materials, the formulation of new laws and the co-ordination of numerous and complex mechanical and electrical factors, Dr. Weston finally developed a line of successful soft-iron instruments which were first placed on the market in 1907.

While these investigations were going quietly forward, other makers were producing various forms of soft-iron instruments, many of which were copied from some of the early Weston models, and selling them with all sorts of absurd claims for accuracy. Enormous numbers of these inferior and misrepresented instruments have been sold, with the result that the soft-iron instrument has come to be regarded as extremely inaccurate, and, worst of all, the numerous errors are universally assumed to be inherent to the type.

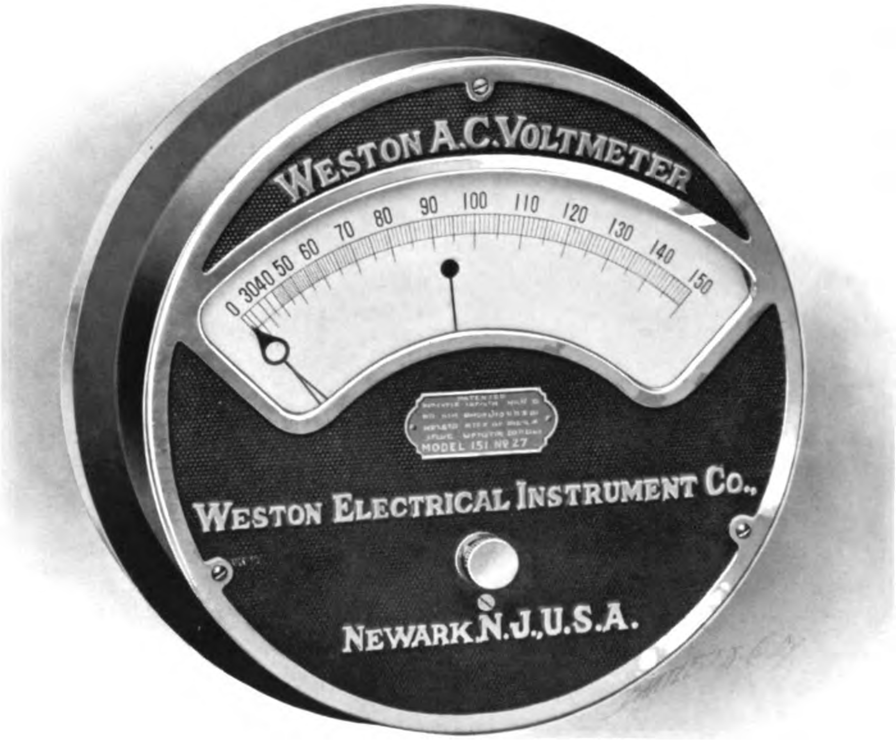

Fig. 59. Model 151 Voltmeter

Thus it is seen that the introduction of the Weston soft-iron instruments, in 1907, found the public in a state of mind quite similar to that existing at the time of the introduction of the Weston permanent magnet instrument, that is, strongly prejudiced against the type.

Weston Soft-Iron Instruments

The introduction of the Weston alternating-current soft-iron voltmeters and ammeters marked the beginning of a new epoch in the art of electrical measurement. Previous to this time no satisfactory alternating-current instruments of this type had been available for switchboard use. By developing these alternating-current instruments, Dr. Weston has added one more item to the long list of his important contributions to electrical science.

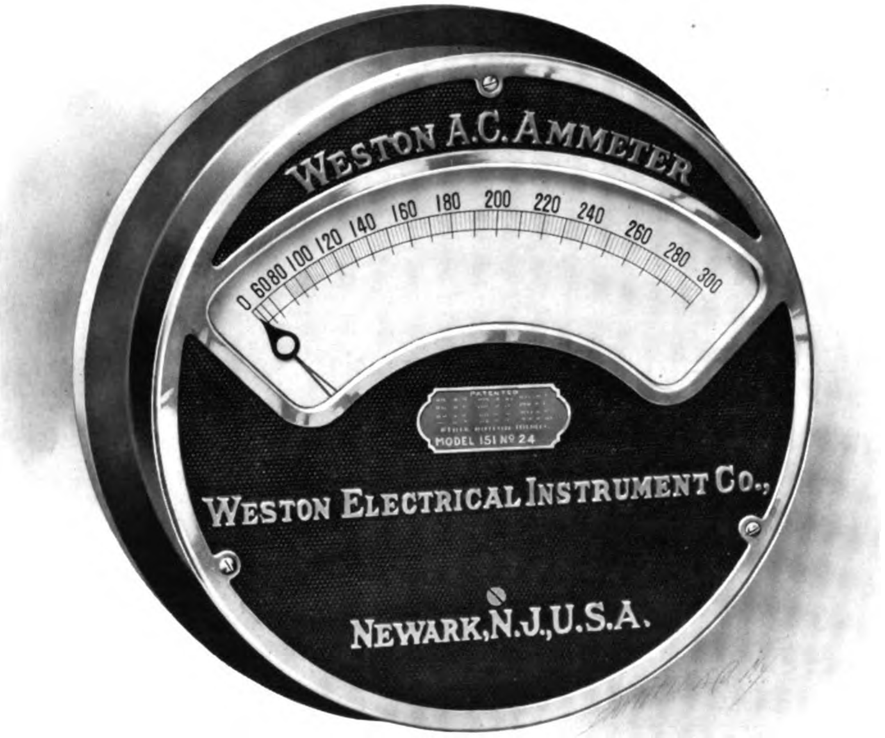

Fig. 60. Model 151 Ammeter

These Weston soft-iron alternating-current switchboard voltmeters and ammeters are the result of prolonged study, the most painstaking mathematical analysis, and of exhaustive scientific research of the many very complex problems involved in devising, designing and constructing instruments intended to give really accurate indications of the value of the forces acting on alternating-current circuits, under the many variable and most trying conditions necessarily met with in practical work.

Particularly is this true of the voltmeters. For it is the voltmeter (whether intended for switchboard use or for service as a portable instrument) in which the inventor, designer and constructor are confronted with so many of the most complex causes of serious error, that a satisfactory solution of the problem seems more and more impossible the closer the subject is studied.

There are almost innumerable types and forms of alternating-current voltmeters in extensive use throughout the civilized world. Most of these instruments are really nothing more than the crudest forms of voltage indicators, and the very best of them exhibit errors of from 4 to 10 per cent, or even much more, under the normal, widely varying conditions of fair, practical use, while under the numerous trying conditions incidental to general use, many of the very best of them exhibit far greater errors. It is impossible in this brief circular to describe in detail the numerous causes of error in the various forms of alternating-current voltmeters now on the market, but it is a fact that the errors they exhibit should only be permissible in the crudest kind of work, and certainly should not be tolerated on lighting, or even on power circuits, where economy of operation or uniformity of result is either essential or desirable.

The existence of serious errors in alternating-current voltmeters is well known to many skilled in the art of electrical measurement, and the causes of some of the errors are doubtless also well known, while the causes of others have hitherto been entirely overlooked. The causes of these errors, so far as they have been known, are frequently assumed and stated to be inherent in the respective types, and are believed to be wholly unsurmountable or irreducible to any appreciable extent. By careful research it has been demonstrated that these assumptions and statements are totally wrong in many respects, and in other respects they are in great part also wrong, though they were certainly justified by experience with all the prior existing alternating-current voltmeters of this type now on the market or in general use.

Advantages of the Weston Instruments

In the light of experience with previous types of alternating-current ammeters and voltmeters, the performance of these Weston instruments appears little short of marvelous. Some of the leading characteristics are enumerated below:

1. The indications are practically independent of frequency and wave form within the limits of engineering practice of to-day.
2. The indications are unaffected by the length of time the instrument is in circuit.
3. The indications are practically independent of changes in room temperature.
4. The readings can be made with substantially the same accuracy on violently fluctuating loads as on steady loads.
5. The scale is open and fairly uniform throughout ⅘ of the total range of deflection.
6. The power consumption is negligible.
7. The instrument has great durability and permanency of calibration.

Frequency and Resonance

By reducing inductance, capacity and eddy currents to very low values, the electrical effects of changes in frequency are avoided. The ordinary instruments all have these errors to a large degree; in fact, no other instrument can be used for all commercial frequencies without change of calibration. The ammeters may be used with frequencies far above the commercial range; for instance, ammeters up to 75-amp. range are used with frequencies up to 1000 cycles per second without change of calibration, and yet these instruments are accurate within 1 per cent. The voltmeters may be used on circuits operating at 150 cycles and still introduce no error as great as 1 per cent. Special voltmeters of this type we have built for use on circuits operating at frequencies as high as 600 cycles per second.

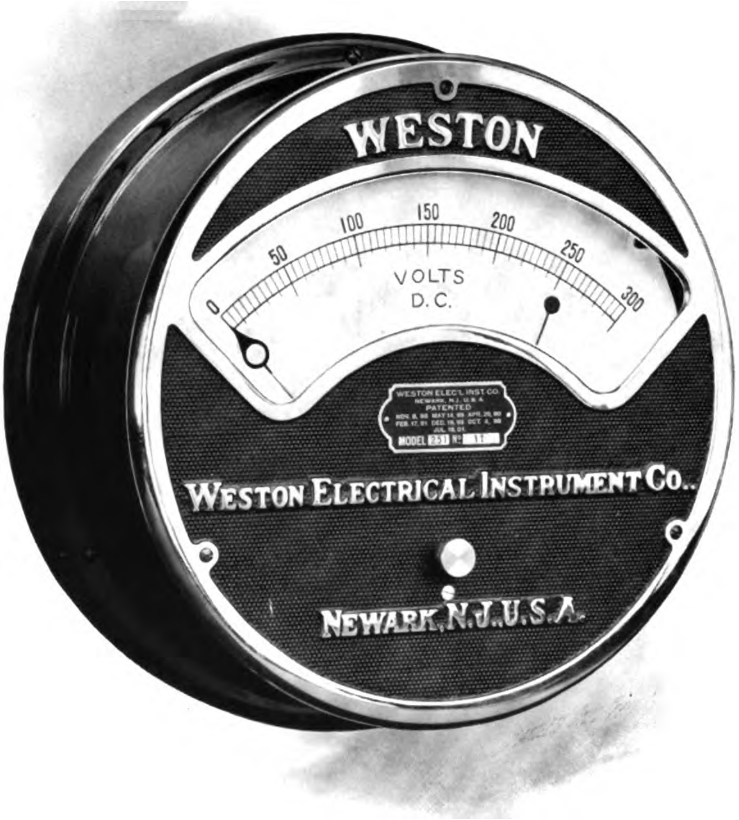

Fig. 61. Model 251 Voltmeter

In all alternating-current instruments the movable system is subjected to the action of forces, which alternate at double the frequency of the electric circuit, and whenever this frequency coincides with the natural fundamental or harmonic vibration of the moving system, or any part thereof, resonance will occur and the pointer be set into violent oscillation. Weston meters may be subjected to any frequency inside the commercial range without the slightest trace of vibration of the pointer. Resonance and many other factors which influence design are discussed in Section 2 of this catalog.

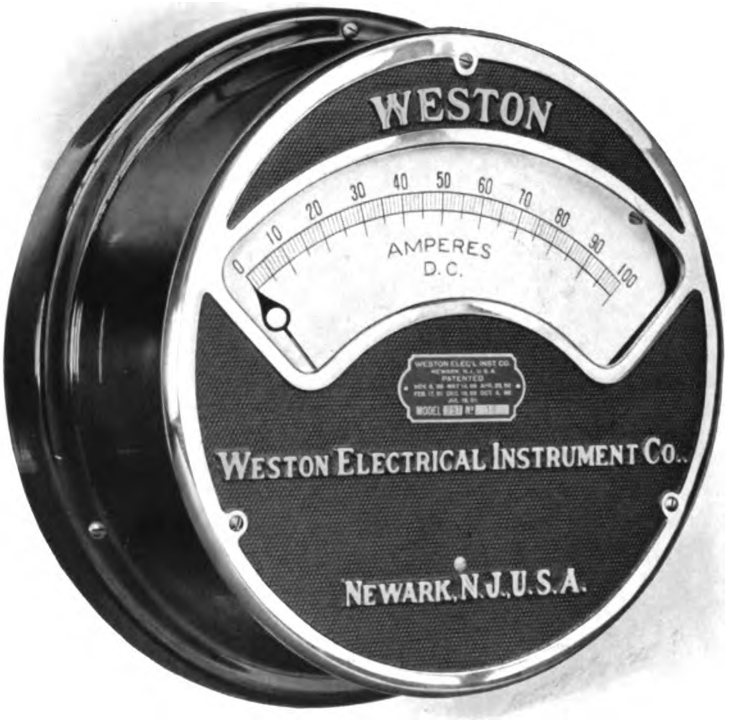

Fig. 62. Model 251 Ammeter

Working Error

By using special conductor materials and designing the circuits for proper temperature distribution and cooling, the working error is reduced to a value not discernible on the scale; that is, the indications are precisely the same whether the instrument remains in circuit a second or permanently.

Chamber Error

By chamber error is meant the error due to changes in the temperature of the air surrounding the instrument. The temperature of electric stations often reaches almost unbearable values, which are far above the temperature at which the instruments were calibrated, and, therefore, very large errors may be caused thereby. In the Weston voltmeters and ammeters this error is entirely negligible; for instance, a 150-volt voltmeter shows an error of only ⅓ per cent for 106 deg. fahr. rise in room temperature. This is quite a wonderful achievement when it is considered that even the best of other makes of this type will show an error of from 4 to 10 per cent under the same conditions, while inferior instruments will show still greater error.

Scale

The scale of alternating-current voltmeters and ammeters is notoriously bad, and before the advent of these Weston meters a non-uniform and haphazard sort of scale was thought to be inherent to nearly all types. The scales of these meters are not absolutely uniform, but they are almost uniform for about ⅘ of the total range and practically uniform throughout the working range, as will be seen from the facsimile scales shown herewith.

Power Consumption

The power consumption has been reduced to a truly negligible value without any sacrifice of accuracy of the indications. It is extremely difficult to reduce the power consumption in alternating-current voltmeters without unduly increasing the inductance, and in the achievement of this result the Weston alternating-current voltmeters stand alone.

Durability

Under the conditions of normal service the useful life of an instrument is limited by the wear at the pivots, and as was explained in the introduction, Section 1, this wear is a function of the weight and amount of motion of the movable system. In these instruments the movable system weighs only 1.6 grams. How remarkably low this figure really is may be understood when we know that among the best switchboard ammeters and voltmeters now on the market, the lightest movable system weighs 2.8 grams, slightly less than twice as much as that of the corresponding Weston instrument. This is of European make. The American instruments are much worse, the nearest approach to the Weston on the score of weight of the movable system being about 6 grams.

A light-weight movable system in which the masses are properly distributed will require little torque to enable it to follow instantly and accurately every fluctuation of the load. It will also lend itself to efficient and effective damping. Reducing weight has been too strenuous a task for many makers, and therefore they were obliged to use higher torque to overcome the friction. High torque and high friction usually go together, and no one should be misled by the phrase "high torque," so often used to characterize certain types of instruments. High torque in itself has no direct bearing on the merits of an instrument; it is the ratio of torque to weight that counts, and here is where the Weston instruments excel.

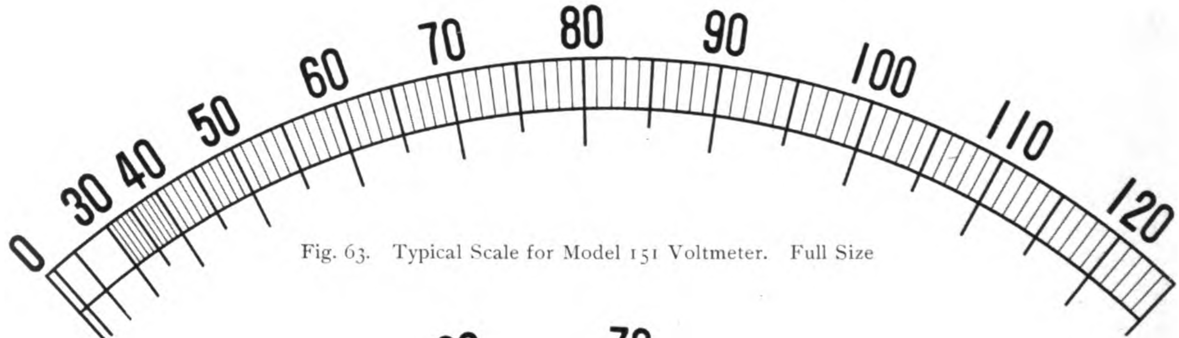

Fig. 63. Typical Scale for Model 151 Voltmeter. Full Size

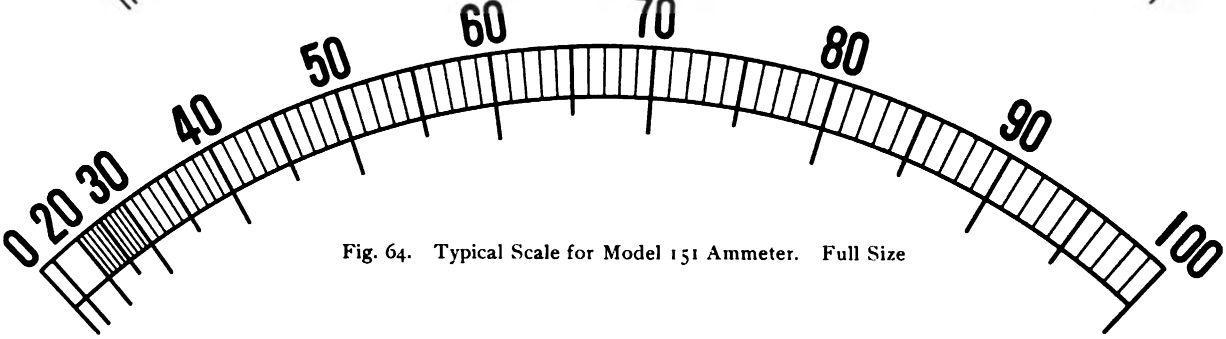

Fig. 64. Typical Scale for Model 151 Ammeter. Full Size

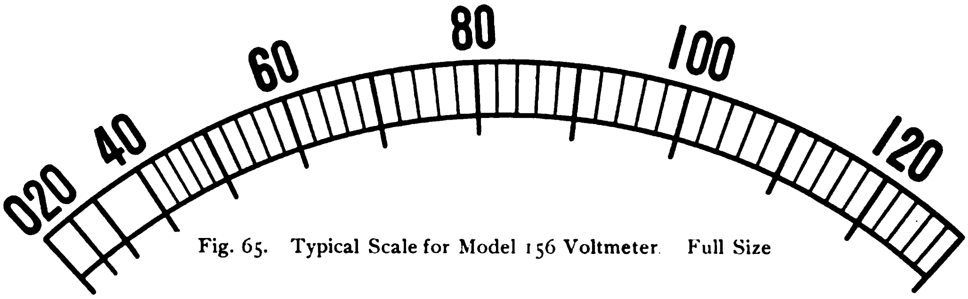

Fig. 65. Typical Scale for Model 156 Voltmeter. Full Size

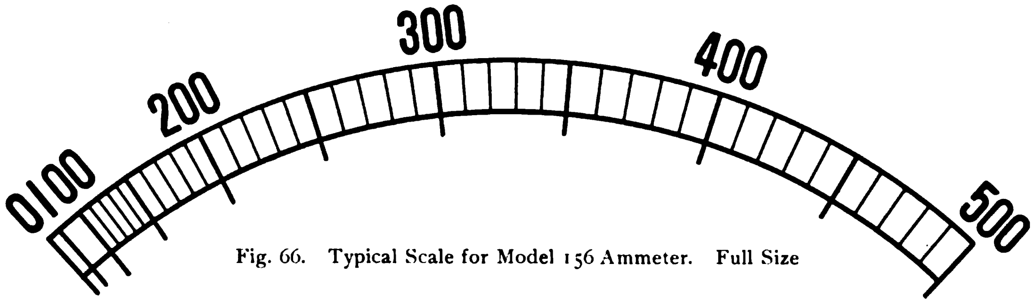

Fig. 66. Typical Scale for Model 156 Ammeter. Full Size

Ranges

Both models 151 and 156 voltmeters are made for seven different ranges corresponding to the scales shown on pages 94 and 97. For e. m. fs. extending from 75 to 750 volts the instruments may be direct connected to the circuit. Any ranges above 750 volts may be had by using potential transformers. Special ranges may be had on request. On special request we have made voltmeters of this type for 35 and 50 volts.

Models 151 and 156 ammeters are made for 19 different ranges, as shown by the scales exhibited on pages 95 and 98. Up to and including 500 amp. they may be had for direct connection to the circuit; above this value current transformers must be used. Current transformers must also be used on circuits above 2300 volts. In all cases where transformers are used, 5-amp. instruments are recommended. Models 151 and 156 differ from each other simply in dimensions, as is shown in dimensional sketches at the end of this section.

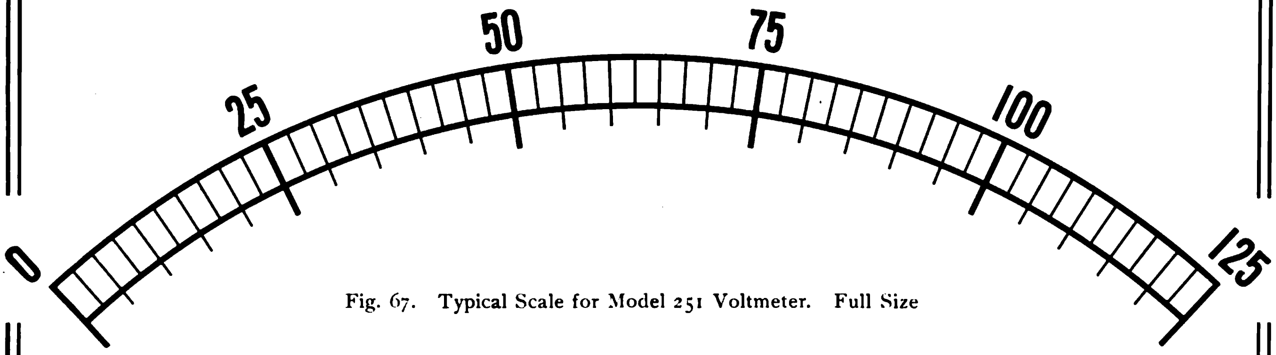

Fig. 67. Typical Scale for Model 251 Voltmeter. Full Size

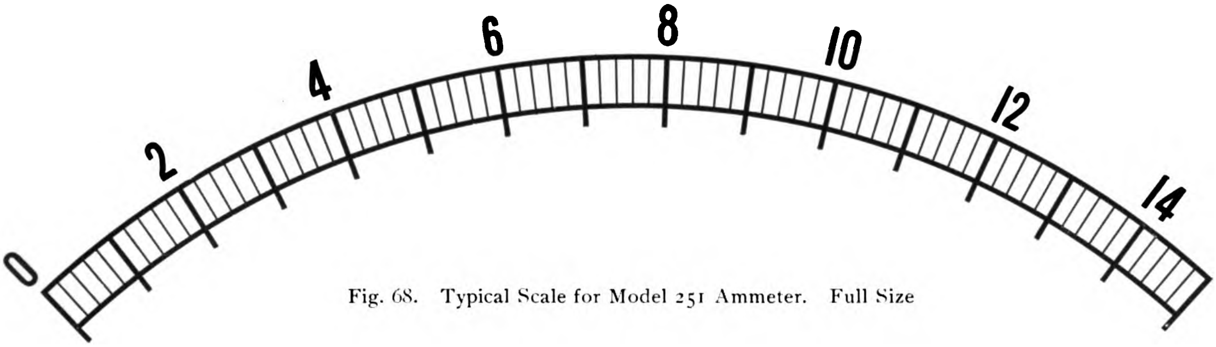

Fig. 68. Typical Scale for Model 251 Ammeter. Full Size

For use on exciter panels and other direct-current panels, which may form a part of an alternating-current switchboard, a special form of permanent magnet moving coil instrument has been developed. These instruments are mounted in sheet steel cases having the same design and base and front dimensions as the Weston alternating-current switchboard wattmeters, etc. They are designated as Model 251.

D. C. Voltmeters and Ammeters

It is unnecessary here to point out the advantages of these instruments, since the Weston permanent magnet instruments are already very well known. The appearance of this new form of instrument is shown in Figs. 61 and 62, pages 87 and 88. It will be noticed that the scales are drawn in to harmonize with those used on the alternating-current instruments and that the terminals are the same as those of the alternating-current soft-iron voltmeters. The ranges at present available are given in the price list.

Price List of Model 151 A. C. Voltmeters

Volts	Code Word	List Price	Volts	Code Word	List Price
75	Largacvo	$18.50	500	Largacvom	$26.50
125	Largacvme	18.50	600	Largacvost	27.50
150	Largacver	18.75	750	Largacvenk	30.00
300	Largacvult	22.50			

Price List of Model 151 A. C. Ammeters

Amperes	Code Word	List Price	Amperes	Code Word	List Price
1	Largac	$17.75	50	Largacaret	$17.50
2	Largacert	17.50	75	Largacam	17.50
3	Largacess	17.00	100	Largacele	17.50
5	Largacant	17.00	150	Largaceter	18.00
10	Largacarl	17.00	200	Largacemt	18.50
15	Largacabe	17.00	250	Largacepet	18.75
20	Largaction	17.00	300	Largaceby	19.00
25	Largacager	17.00	400	Largacgy	19.00
30	Largacper	17.00	500	Largaclow	20.00
40	Largacgon	17.50			

Price List of Model 156 A. C. Voltmeters

Volts	Code Word	List Price	Volts	Code Word	List Price
75	Smalacvice	$14.50	500	Smalachev	$19.50
125	Smalacvan	14.50	600	Smalacane	21.00
150	Smalacast	14.75	750	Smalacint	23.50
300	Smalachest	18.50			

Price List of Model 156 A. C. Ammeters

Amperes	Code Word	List Price	Amperes	Code Word	List Price
1	Smalace	$14.00	50	Smalacul	$13.75
2	Smalachen	13.75	75	Smalacust	13.75
3	Smalachic	13.50	100	Smalacub	13.75
5	Smalacent	13.50	150	Smalacri	14.25
10	Smalacan	13.50	200	Smalachn	14.75
15	Smalacif	13.50	250	Smalacist	15.00
20	Smalacage	13.50	300	Smalacig	15.50
25	Smalacarn	13.50	400	Smalacex	16.50
30	Smalacone	13.50	500	Smalacate	17.50
40	Smalacart	13.75			

Price List of Model 251 D. C. Voltmeters

Volts	Code Word	List Price	Volts	Code Word	List Price
125	Exacvo	$28.25	300	Exacvop	$32.50
150	Exacvit	29.50	600	Exacvun	35.00
250	Exacvel	31.50	750	Exacvex	37.00

Price List of Model 251 D. C. Ammeters

Amperes	Code Word	List Price	Amperes	Code Word	List Price
5	Exacam	$25.00	200	Exacamal	$28.00
10	Exacamper	25.00	250	Exacamut	28.25
15	Exacamput	25.00	300	Exacamalt	28.25
25	Exacamit	25.00	400	Exacampil	28.50
50	Exacamter	25.50	500	Exacamo	29.50
75	Exacamig	26.00	600	Exacami	30.50
100	Exacamun	26.50	750	Exacamp	31.50
150	Exacamez	27.00			

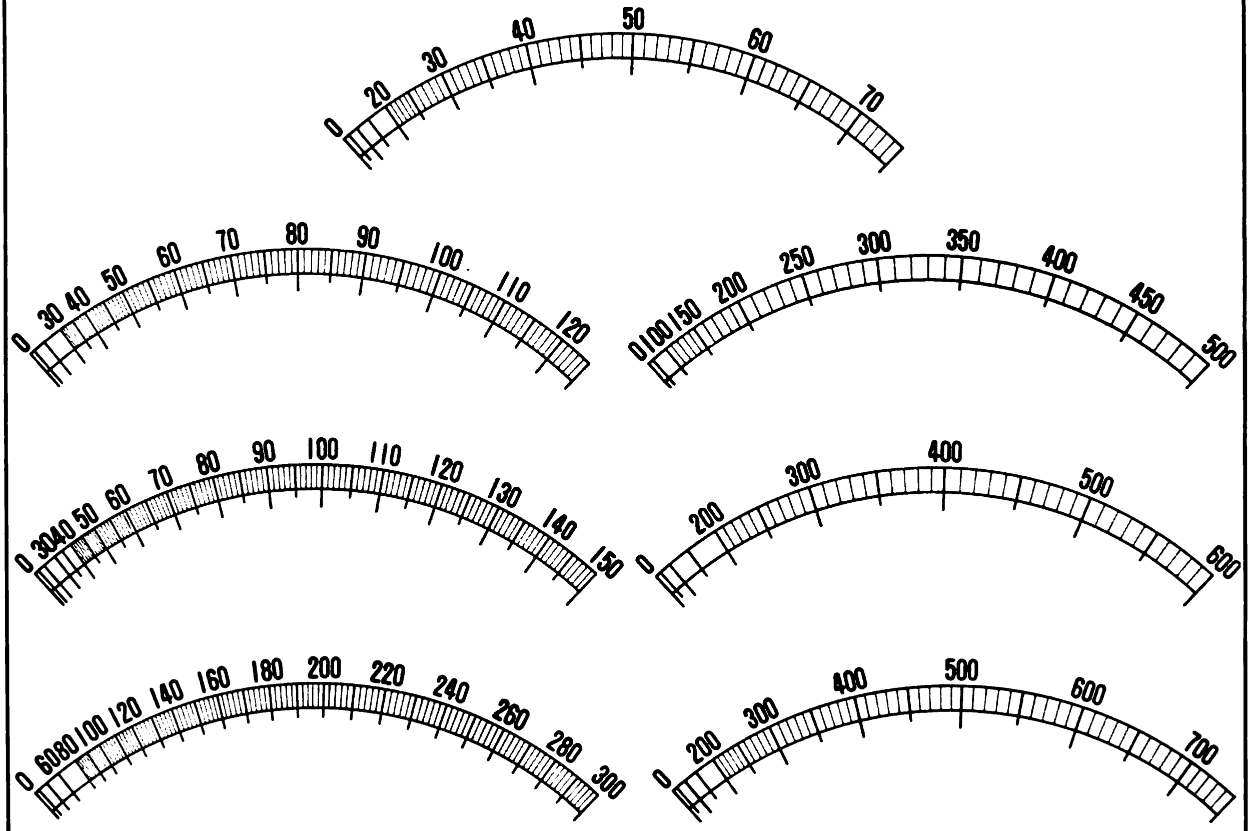

Fig. 69. Standard Scales for Model 151 Voltmeters. Reduced Size

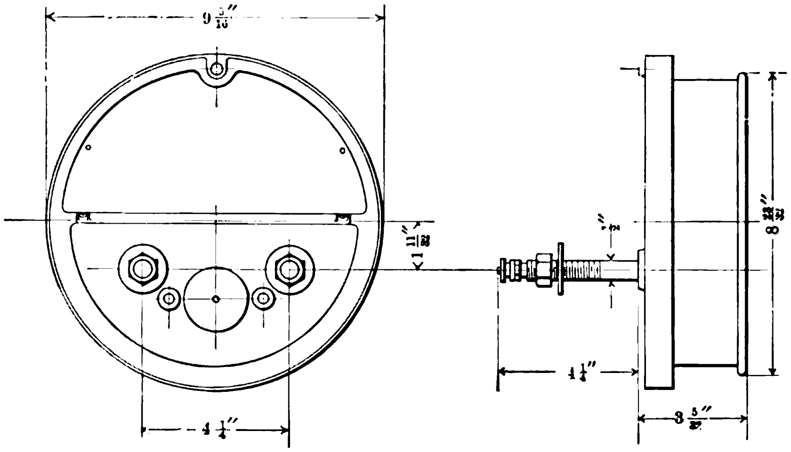

Fig. 70. Dimensions of Model 151 Voltmeter

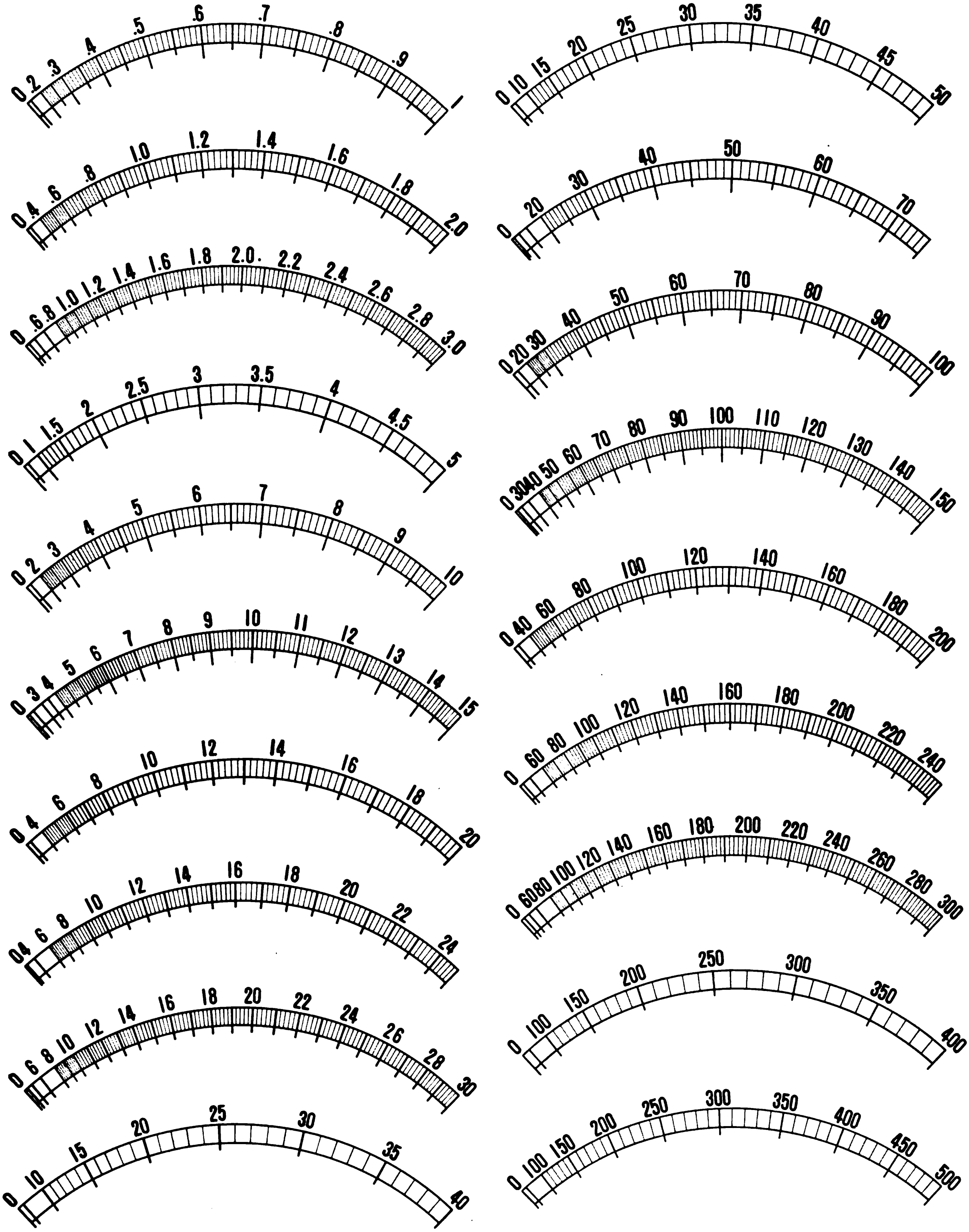

Fig. 71. Standard Scales for Model 151 Ammeters. Reduced Size

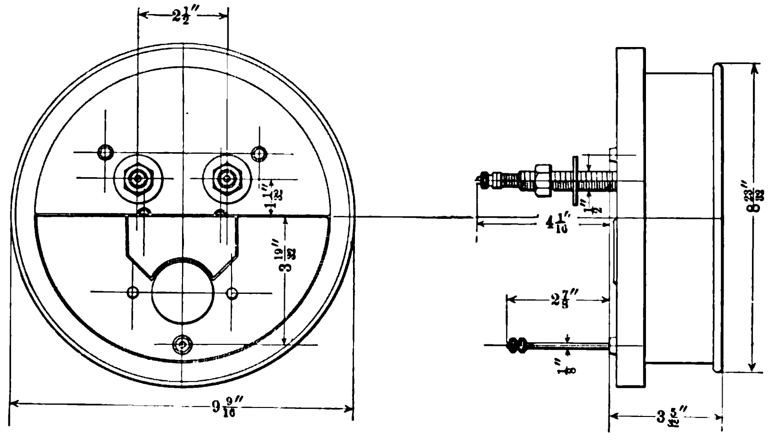

Fig. 72. Dimensions of Model 151 Ammeter. Range, 1 to 40 Amperes Inclusive

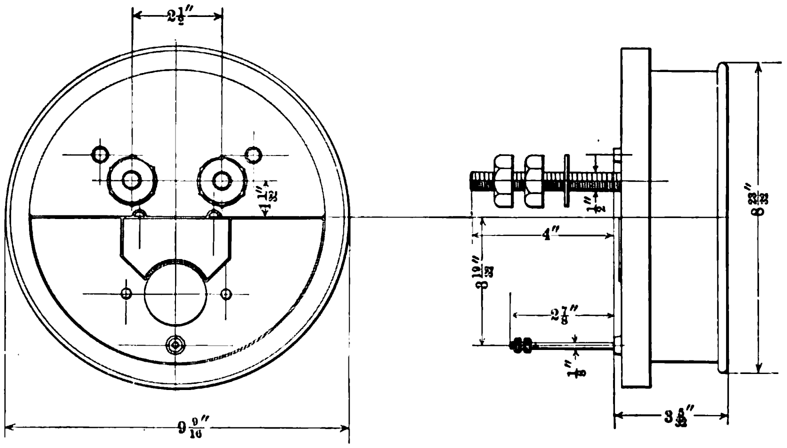

Fig. 73. Dimensions of Model 151 Ammeter. Range, 50 to 300 Amperes Inclusive

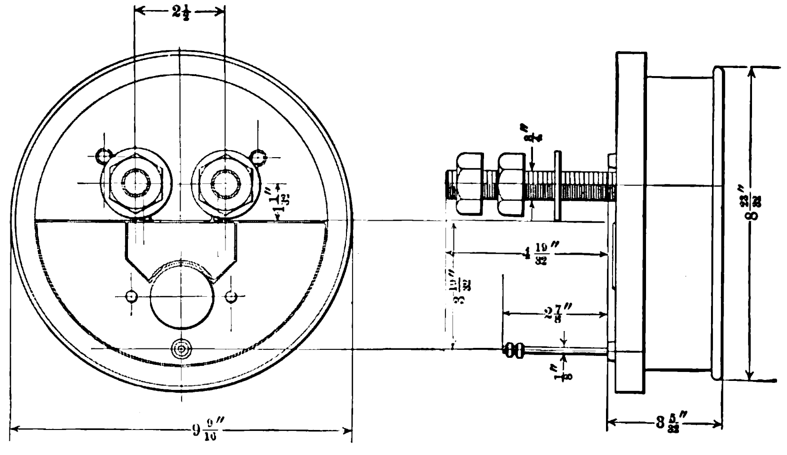

Fig. 74. Dimensions of Model 151 Ammeter. Range, 400 to 500 Amperes Inclusive

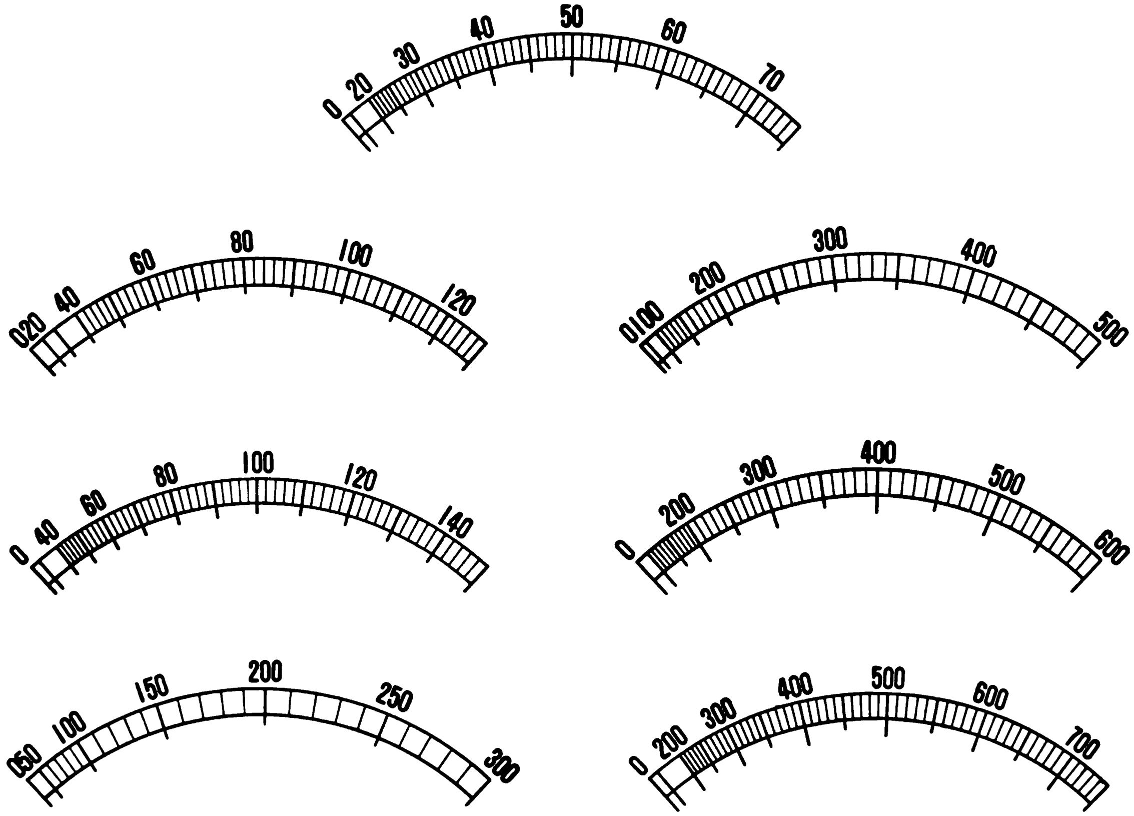

Fig. 75. Standard Scales for Model 156 Voltmeters. Reduced Size

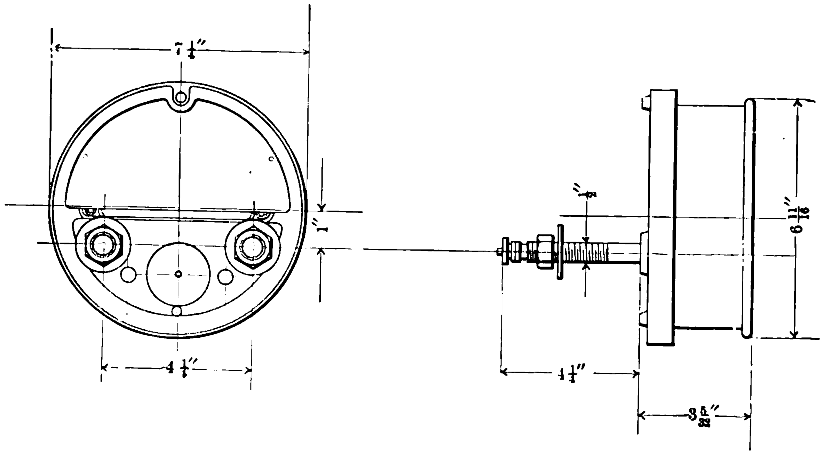

Fig. 76. Dimensions of Model 156 Voltmeter

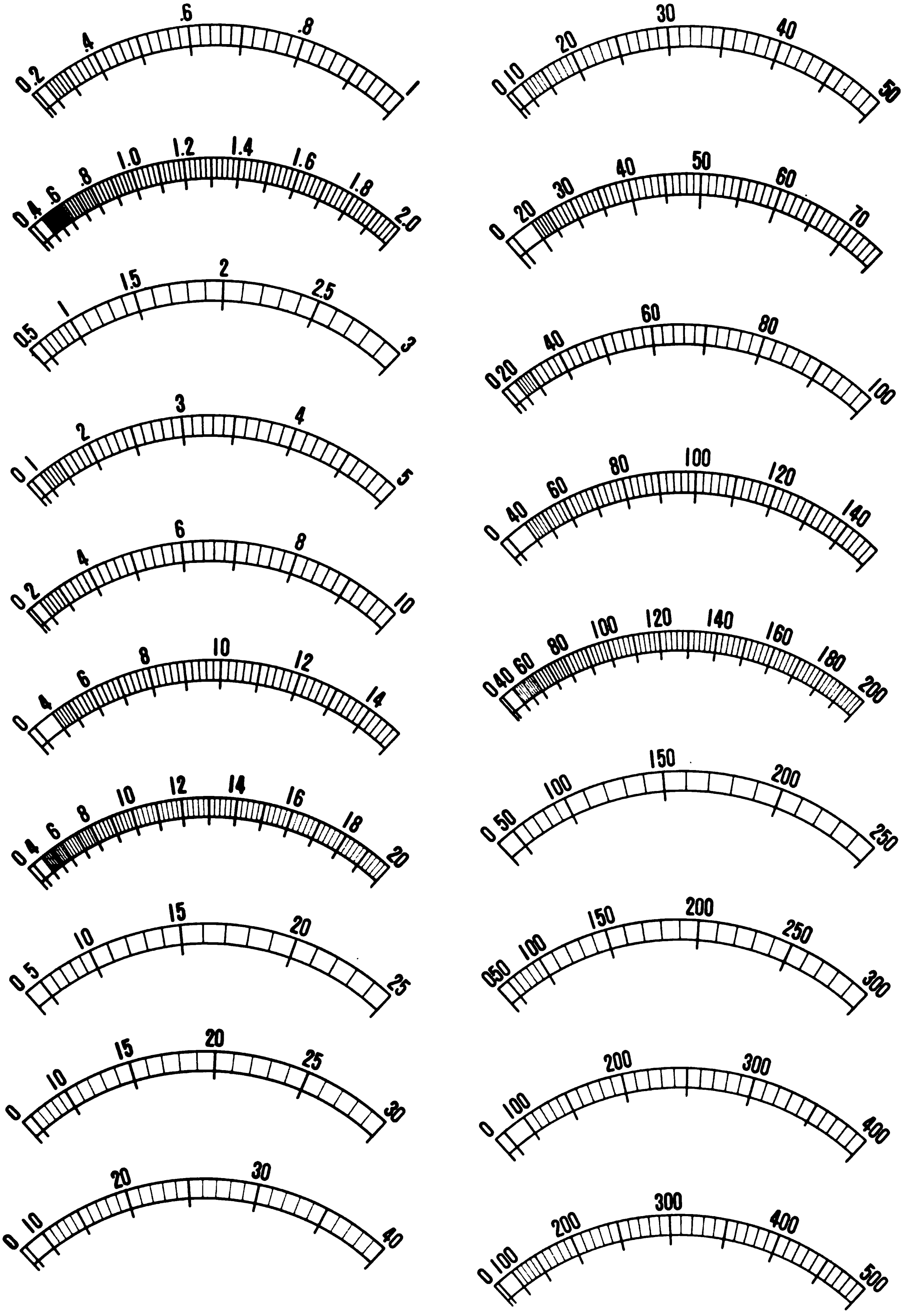

Fig. 70. Standard Scales for Model 156 Ammeters. Reduced Size

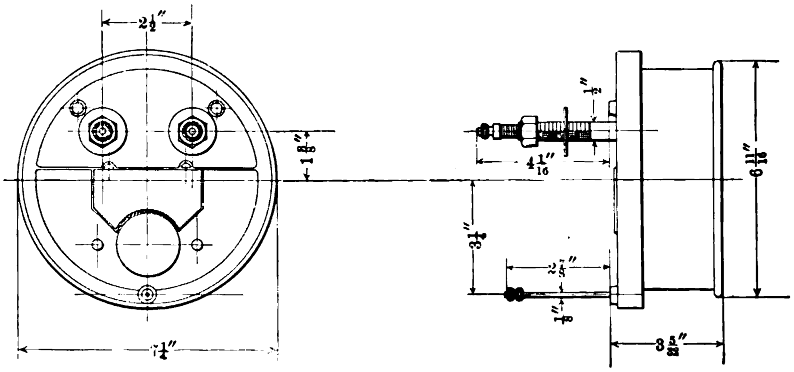

Fig. 78. Dimensions of Model 156 Ammeter. Range, 0 to 40 Amperes Inclusive

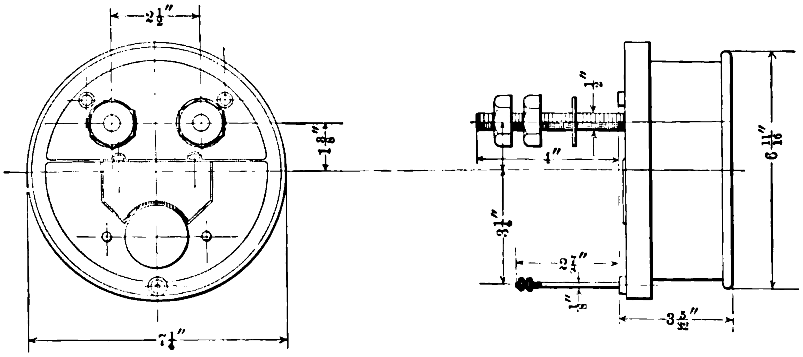

Fig. 79. Dimensions of Model 156 Ammeter. Range, 50 to 300 Amperes Inclusive

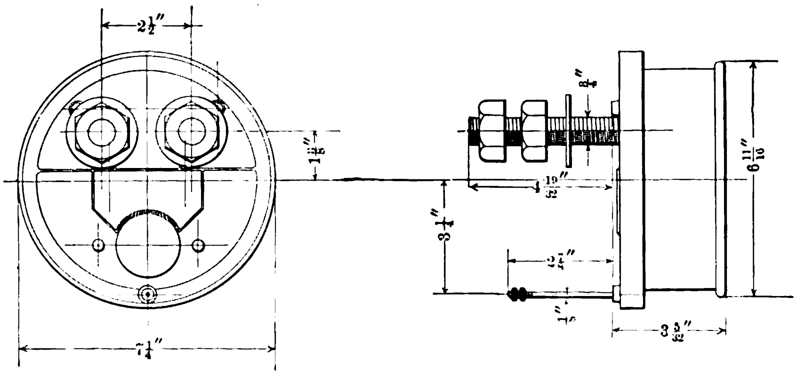

Fig. 80. Dimensions of Model 156 Ammeter. Range, 400 to 500 Amperes Inclusive

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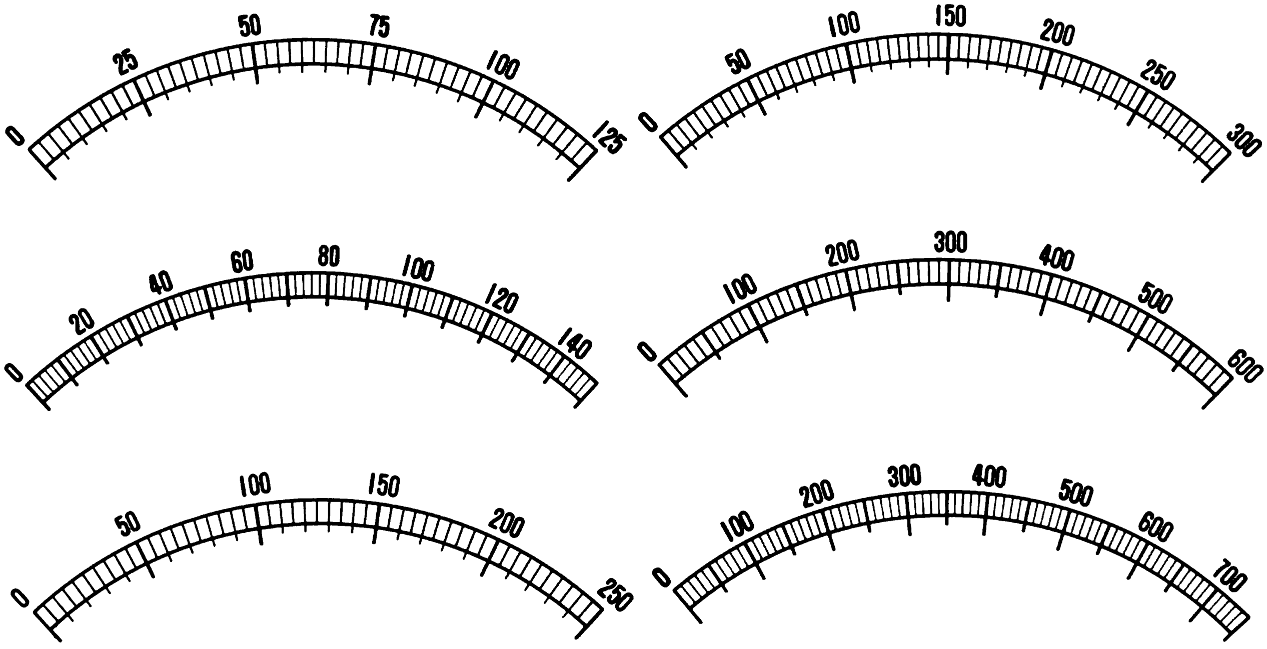

Fig. 81. Standard Scales for Model 251 Voltmeters. Reduced Size

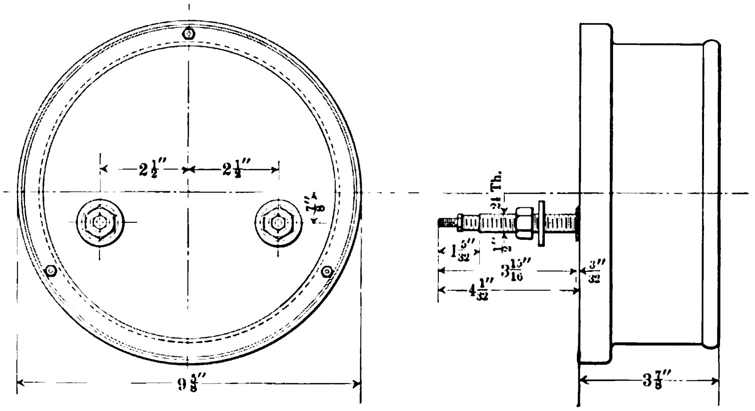

Fig. 82. Dimensions of Model 251 Voltmeters and Ammeters

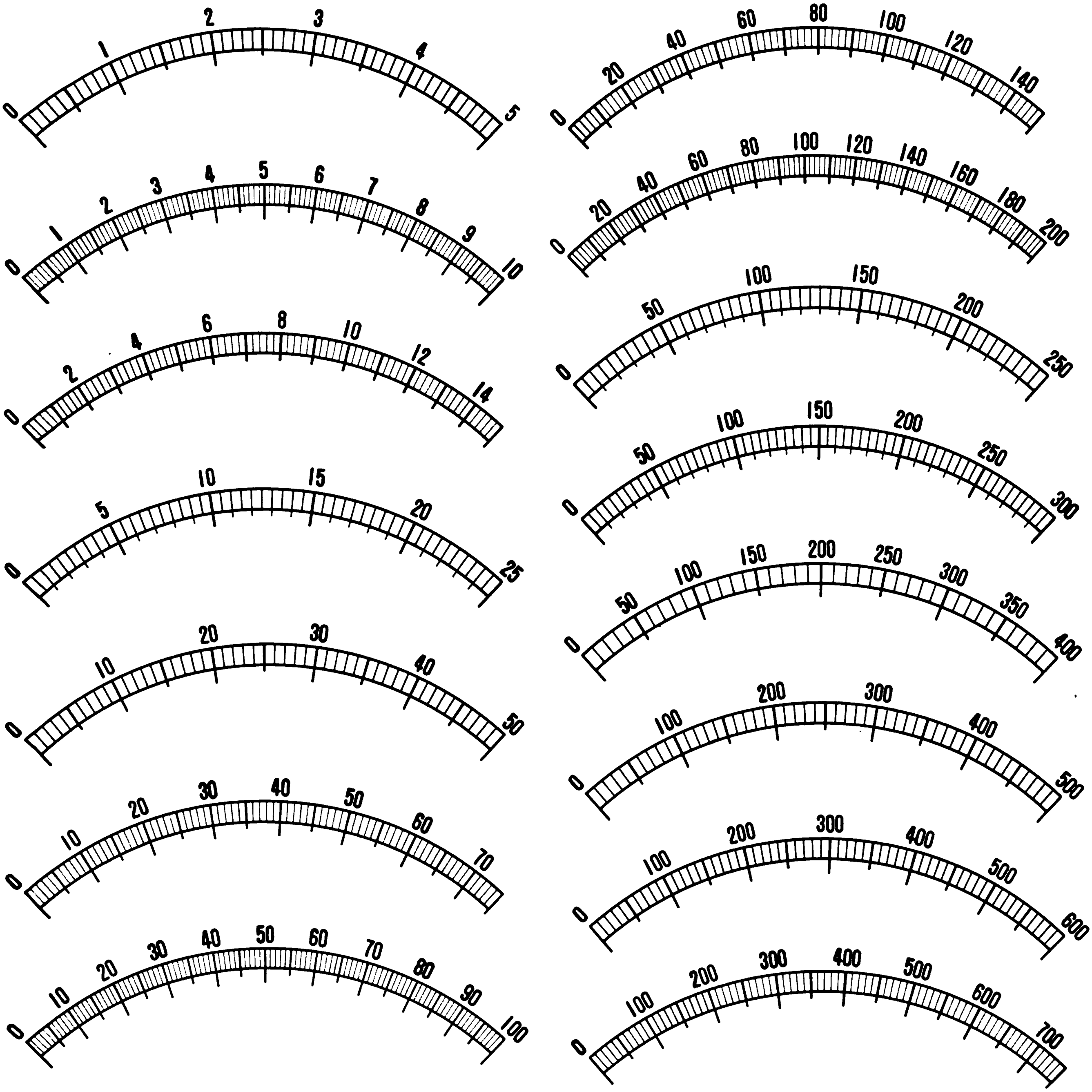

Fig. 83. Standard Scales for Model 251 Ammeters. Reduced Size

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